

OPENFLIGHT DATABASE CONVERSION FOR DISTRIBUTED MISSION TRAINING PC-BASED IMAGE GENERATORS

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Abstract

Distributed Mission Training (DMT) F-15C Program has been underway to augment existing USAF joint training capabilities. Each DMT F-15C site consists of four full-field-of-view Visual Integrated Display Systems (VIDS's) driven by high-end ESIG-4530GT image generators (IGs). Also parts of each DMT F-15C site are desktop PC-based IGs networked with the ESIGs. The challenge is to achieve visual correlation using IGs and databases (DBs) of such widely differing performance levels and architectures. This paper describes a DB conversion process jointly developed by Boeing, Westar, Evans and Sutherland (E&S), and Terrain Experts. One of several challenges was polygon co-planarity, however, cutting coplanar polygons into the underlying layers by an Automated Database Generation and Reconstruction Tool solved the problem. Excellent degree of correlation, accuracy, and PC-based IG update rates have been achieved for the Eglin, Nellis, Langley, and Southwest Asia databases, indicating a significant potential for cost-saving re-use of existing databases by PC-based image generators.

Biographical Sketches:

Budimir Zvolanek is a Boeing Associate Technical Fellow responsible for visual/NVG/IR/radar image and database generation, auto tracking, and image exploitation development at Boeing Training and Support (TSS). At Boeing Phantom Works, he developed innovative automatic target recognition and image processing algorithms for missile guidance. He also developed image processing hardware and software at Washington University Biomedical Computer Laboratory, where he received his MS and BS in Elec. Engineering. Budimir has published extensively, receiving two I/ITSEC Best Paper Award Nominations.

Donna Allen is the Lead Visual Database Modeler for the Boeing-Philadelphia Flight Simulation Laboratory supporting aircraft handling qualities and human factors visual DB modeling requirements for the Tandem Rotor Chinooks, V-22 Osprey, RAH Comanche, AH-64D Apache, and Heliwing UAV. Donna has been cited for her work in high-density civilian urban database development and 3-D modeling. She has been the Project Manager for multi-site visual DB modeling activities supporting the Training & Support Systems DMT F-15C Program. She received BS in Mathematics Education from SUNY Cortland and MS in Computer Science from Villanova University.

William Paone is Sr. Dev. Engineer at Westar Corporation, PureLogix Division, in St. Louis, Missouri, developing image generation software and databases for the Boeing VIDS* Product Center. Bill has pursued real-time hardware and software development in commercial and military arenas with major emphasis on imaging systems for cockpit displays and out the window scene generation. Other areas include telecommunication system, hardware, and software development in American and European markets, system production and test management, and hybrid microcircuit production engineering. Bill received his BS in Electrical Engineering from the University of Missouri at Rolla.

Richard Clark is a Vice President of Product Development at Terrex. He has led the Terra Vista* product development team from conception through four major product releases. Before this, Richard was Director of Engineering at MultiGen Inc., leading the Multigen* product through five major software releases when the installed base and market position of the Multigen grew dramatically. He managed the technical, financial, and personnel aspects of the entire engineering department. Mr. Clark developed much of the code and led the early MultiGen efforts in terrain processing. His credits include authorship of the DfadGen standalone cultural editor and of other terrain-related options to Multigen*. Mr. Clark holds a Bachelors Degree from the University of California - Los Angeles, CA.

OpenFlight Database Conversion for Distributed Mission Training PC-Based Image Generators

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INTRODUCTION

Migration of high-end image generation capabilities for 3-D virtual environments to low-cost PC-based platforms is undeniable. Accompanying this trend is also the need for PC-based IG databases that correlate with the high-performance IG databases - such as under the Distributed Mission Training (DMT) F-15C Program. Rather than starting from source data, such as National Imagery and Mapping Agency (NIMA) Digital Terrain Elevation Data (DTED*, 1986) and Digital Feature Analysis Data (DFAD, 1986), the development of PC IG databases from the high-performance IG databases by format conversion can be attractive when accomplished without significant loss of image fidelity, correlation, and when performed quickly and affordably.

It is important to note that DB re-use has already been advocated and demonstrated by US Government sponsored DB interchange efforts, such as the mature Standard Simulator Database Interchange Format MIL-STD-1821 (SIF, 1993) or the still evolving Synthetic Environment Data Representation and Interchange Specification (SEDRIS, 1999). However there is no SIF or SEDRIS requirement for the DMT F-15C Program and so direct conversion from native ESIG* to PC IG OpenFlight format was developed instead. More importantly, irrespective of whether SEDRIS, SIF, or direct DB export from ESIG *General Database Format* (GDF*) using E&S EaSIEST tools are used, conversion into OpenFlight and optimization for the run-time PC IG platform

performance is still required. Therefore, the method of direct export from GDF* into OpenFlight was used.

One of the major technical challenges faced in the conversion of ESIG-4530GT IG databases into PC-based IG OpenFlight databases is polygon co-planarity. ESIG-4530GT is characterized by the Binary Separating Plane (BSP) polygon prioritization while PC IGs use the z-buffer approach. When transforming databases from the BSP-based ESIG GDF* into OpenFlight format, many co-planar polygons result in the OpenFlight format that are not resolvable by the z-buffer architecture and thus cause highly distracting polygon flashing. However, 'cutting' problematic polygons into underlying polygon layers can solve the co-planarity problem. The issue is then an efficient and quick process to provide this function. Other hurdles to overcome are resultant high polygonal densities and large amounts of ESIG* geospecific (global) texture mapped in real time onto the polygons by the ESIG* that can easily overload the PC IG.

This paper describes a correlated database (DB) conversion process jointly developed by Boeing, Westar, Evans and Sutherland, and Terrex* under the DMT F-15C program. The process involves format conversion between high-performance and PC-based image generators of very dissimilar architectures – the E&S "GDF*" to industry-standard OpenFlight database formats for out-the-window (OTW) ESIG-4530GT and desktop image generators (IGs), respectively. A satisfactory degree of correlation and accuracy

with acceptable PC-based IG update rates for the DMT F-15C purposes have been achieved, indicating significant potential for cost-savings by re-using existing databases and deploying low-cost PC-based image generators to training systems. The paper continues below with background on the DMT F-15C application and database differences for dissimilar DMT F-15C image generators. The GDF*-to-OpenFlight DB conversion process is then described followed by DB conversion results and impact on affordable image generation by database re-use.

BACKGROUND

The DMT F-15C Program has been underway to augment existing US Air Force (USAF) training capability in both local-site and long haul networked DMT F-15C modes. Each "four-ship" DMT F-15C site consists of four simulator cockpits placed within a full field of view (FFOV) Visual Integrated Display System (VIDS*) developed by Boeing. Also part of each DMT F-15C site are the desktop PC-based Threat Station (TS), Instructor-Operator Station (IOS), and Brief-Debrief Station (BDS) simulators networked with the cockpits. One of the DMT F-15C requirements is 3-D visualization of the Out-The-Window (OTW) visual synthetic environment by the VIDS*, TS, IOS, and BDS systems.

One of the DMT F-15C challenges has been to achieve visual correlation and accuracy using image generators of widely differing performance levels and architectures. On one end of the spectrum is the high-performance, seven-channel ESIG-4530GT image generator serving the 360-degree FFOV VIDS*. On the other end is a PC-based, 3-D graphics card, single-channel image generator for the TS, IOS, and BDS desktops. Nevertheless, the challenge has been successfully met due to very recent advances in PC-based IG performance and database development technologies.

The work performed under the DMT F-15C Program demonstrates how application of state-of-the-art PC IG DB tools provided the necessary DB correlation, accuracy, and fidelity and enabled the activation of DMT F-15C sites at Eglin and Langley AFBs. Having developed the basic DB conversion process steps, the OpenFlight DB development tools were actually being modified and improved by their supplier as the DB conversion took place at Boeing as a software 'beta site'. In fact, geographically distant Boeing in St. Louis, Philadelphia, and Seattle along with E&S in Salt Lake City and

Terrain Experts, Inc. in San Jose worked together over the Internet as a "Virtual Database Factory" team to define and implement the DB conversion solution for four DMT F-15C databases. This effort also exemplifies how to enrich the "repository" of high-performance databases for PC image generators.

DATABASE CONVERSION PROCESS

The DMT F-15C program requirements resulted in ESIG-4530GT and PC-based 3-D graphics IGs with very different image generation architectures. These included binary-separating planes (BSPs) on ESIG-4530GT vs. Z-buffer priority resolution on PC IG and large disc-based vs. limited online texture memories. The corresponding ESIG* GDF* to PC IG OpenFlight DB conversion process had to account for these differences.

E&S has developed a software tool set for converting the GDF* database into OpenFlight as part of their EaSIEST* DB generation software. However, application of the OpenFlight tool set to a GDF* database resulted in an OpenFlight database with several artifacts that made the conversion output not directly usable by any OpenFlight-capable IG. OpenFlight DB post-processing and clean up became necessary thus splitting the conversion from GDF* to final OpenFlight database into two phases.

Phase 1: Native-to-Preliminary OpenFlight Conversion

The Phase-1 GDF*-to-OpenFlight DB conversion involved ESIG-4530GT Global Textures followed by conversion of terrain skin and 2-D features.

Global texture conversion issues. Initial issues of conversion of the database involved the Global Texture that was applied to the ESIG* GDF* format database. It was not possible to convert the Global Texture to OpenFlight texture files using the Evans & Sutherland conversion tool set. The Global texture is actually applied in real time on the image generator, so it was not available to output from the files in the EaSIEST database building process where the EaSIEST tool set does the conversion (Figure 1). Therefore, the entire database terrain skin had to be rebuilt with polygonal texture, effectively throwing away the ESIG Global Texture. The original projection files and terrain skin were used. The global texture was deleted and polygonal texture was defined for each of the

areal features, including the linear features of the original Global-Textured database (Figure 2).

It was important to keep track of the texture used on each type of polygon throughout the database building process, from the GT database build to the polygonal texture database build. All three database construction sites of the Boeing 'virtual DB factory' - Seattle Integrated Technology Development Laboratory (ITDL), Seattle Commercial, and Philadelphia - maintained a current copy of a reference polygon definition set.

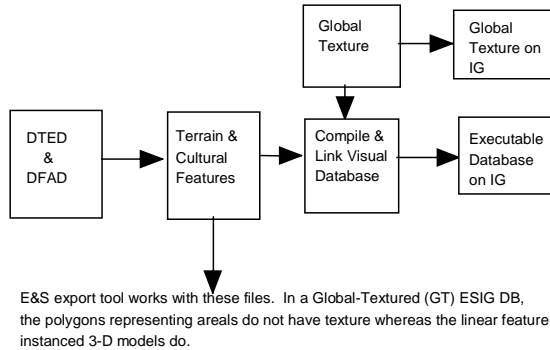


Figure 1. ESIG* Global-Texture (GT) DB Processing

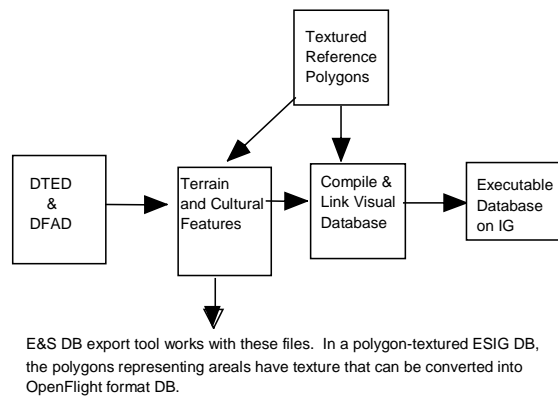


Figure 2. ESIG* Polygon-Texture DB Processing Prior To Conversion

Terrain skin and 2-D features conversion issues. The first attempt at creating the OpenFlight database by converting from GDF* cell mesh files using the EaSIEST* toolkit had problems with the shorelines and land areas. It was discovered that reducing the number of vertices in the DFAD areal actually created gaps in the terrain coverage thus causing slices of land to be in the ocean, ocean in the midst of land, and edges of the ocean to mismatch with the land (Figure 3). This was not a problem in the Global Textured GDF* database but became an issue in the polygon-textured OpenFlight database. As

the tools worked to reduce the number of vertices in the DFAD, not all vertices were marked "shared" and in areas where the DFAD areals abutted one another, different vertices were being deleted, leaving gaps and holes that were not correctly covered on the database build.

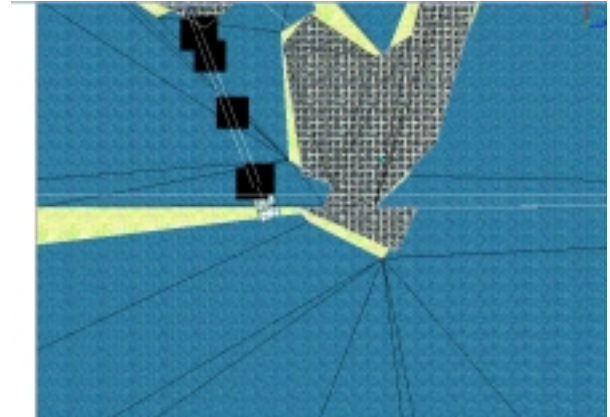


Figure 3. Mismatch along the Shoreline and The Greenish Ground That Crosses the Water on the Left.

This problem was solved by using ESRI's "Arc" Tools that maintained the "shared" vertices and output the data with matching edges along the areals while reducing the number of points in the DFAD areals (Figure 4).

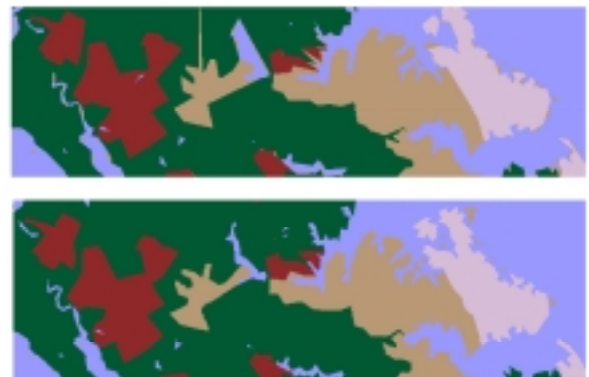


Figure 4. Top Image: DFAD Reduction with Unshared Vertices Results in Gaps and Mismatch along the Edges of the Areal. Bottom Image: Clean DFAD Reduction with Shared Vertices.

However, the resultant output terrain files still had too many polygons for a PC-based image generator. It was therefore necessary to decrease the number of vertices in the DFAD areal data even further. Several trials on a small piece of terrain were run until a subjectively

satisfactory level was achieved. The GDF* and converted OpenFlight databases needed to be as close to 100% correlated as possible.

The last step in Phase 1 was running the *flt_locltex* Multigen* OpenFlight verification utility on each OpenFlight file (terrain parcel) to make sure that all of the textures referenced in each OpenFlight file were called from the same directory as that file.

Phase 2: Preliminary-to-Final OpenFlight Conversion

The initial DB transformation from GDF* provided the initial OpenFlight layered-polygon database with co-planar polygons. Unfortunately, the co-planar polygons were not tagged as 'co-planar' because manual tagging would be impractical for large gaming area databases such as on DMT F-15C. However, we found other indicators of this "co-planarity" problem that could be used. The database from Phase 1 was inspected and, after numerous experiments, polygon textures were found as best indicators of polygon layer priority and co-planarity.

In order to make the preliminary OpenFlight output usable by a z-buffered IG, the top layer co-planar polygons had to be 'cut into' the lower layer polygons. Polygons were 'cut in' using the automated Database Analysis and Reconstruction Tool (DART*) software from Terrex*. By using DART*, a 'Project' is created first to recognize which polygons to cut into the underlying layers. Then DART* performs the DB re-polygonization based on polygonal densities and levels of detail requirements (Figure 5).

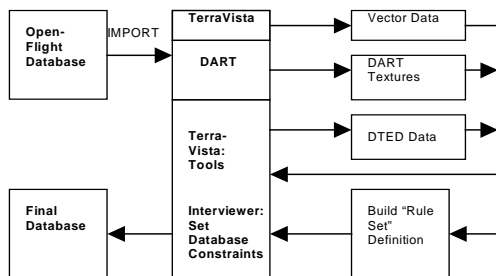


Figure 5. Preliminary-to-Final OpenFlight Format Conversion

Terrex* has developed the DART* software to post-process the preliminary OpenFlight database as part of their Terra Vista* DB generation tool set. DART* takes an unusual approach to the problem of database reuse by treating the original (Phase-1) OpenFlight database converted from GDF* as if it were a

cartographic data source, such as NIMA DFAD, Vector Product Format* (VPF*), or other traditional sources of vector data typically used to construct visual databases. The problem of database conversion is then approached as the generation of a new database from traditional sources. There are several important objectives for this approach:

- Input OpenFlight database polygons are passed through the Terra Vista* terrain generation engine unmodified. The advantage of this approach is that all of the topological operations typically performed on vector data such as de-layering, prioritization, and clipping can then be applied to the OpenFlight terrain polygons. As a consequence polygon co-planarity is eliminated automatically as part of the terrain database process.
- When a terrain database is constructed for a target IG platform, a physical structure is imposed on the polygonal representation of the intended IG virtual world representation for optimal IG performance. This physical structure is used then during run time to perform field-of-view (FOV) culling (i.e., the rejection of certain groups of polygons for rendering because they cannot be seen) and level-of-detail (LOD) switching (i.e., the representation of the same geographic area with fewer polygons). However, FOV culling and LOD switching distances are usually tightly coupled with the target IG hardware and software platform and a different IG platform with different performance characteristics will require a new physical structure be generated.

DART* achieves these objectives by the following technique:

- First, an elevation file is derived from the original input OpenFlight database. The file will be used to construct lower LOD versions of the input database.
- The user then defines a new culling structure for a new LOD structure to be generated.
- The highest level of detail of the original OpenFlight database is used as the highest level of detail of the newly generated database. At the highest level of detail there is 100-percent correlation between the two databases. However, a new, more efficient culling structure is imposed on the new

highest LOD to adapt it to the new IG hardware and software environment.

- Lower LODs are then generated from the elevation file. The number of LODs may be different than in the original input OpenFlight. The lower LODs are represented as Triangular Irregular Networks (TINS) that give a good fit to an elevation surface with a minimal number of polygons - an ideal solution for a target PC-based IG platform. In the example below (Figure 6) notice that the polygons closer in view (from the original database) appear as right triangles whereas those in the distance from the lower LODs are TINs.

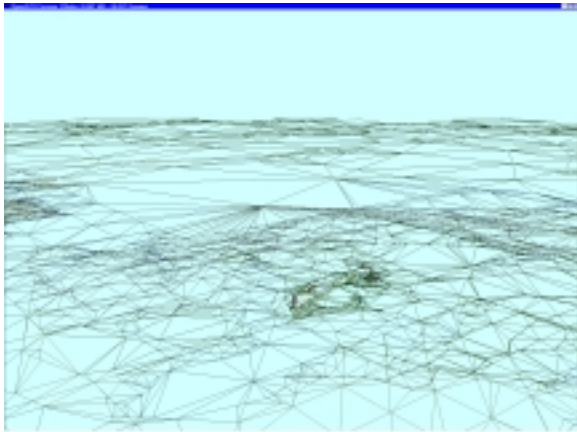


Figure 6. Example of a DART*-Produced Image Showing Near High-Resolution Right Triangles and Distant TINs

Using DART* to complete the database conversion was imperative in this design. This tool allowed us to fix the problems with the preliminary (Phase-1) OpenFlight database and then tune the resultant output OpenFlight (Phase-2) database to the target IG platform. First, the database was imported into Terra Vista*, resulting in an interactive map, or a "Thumbnail", of the area. The Thumbnail allowed us to see the extents of the database and select and check for appropriate cultural and elevation builds. All textures were imported as well and we could actually view the imported texture maps. Once the database was imported, the elevation data was re-built.

We then created the rules of generation for this database. In our case (as discussed above), the rules were mostly designed around the textures assigned to the geometry. These rules allowed us to define the priorities in the database for any OpenFlight parameter to correct co-planarity problems and to "float" 3-D objects. An example is to set the priority for the

texture found in a two-lane road higher than the priority for a grass or forest area and then cut the road polygons into the grass or area.

In fact, any texture can be also made to float and the rules can be made more complex to the point where decision branches can be designed. For instance, if a texture assigned to a road also passes onto a bridge and the priority was assigned to be higher than water and terrain, then the tool would cut the bridge into the river and terrain erroneously. The texture applied to the polygons on the bridge in Figure 7 was changed so that the bridge would float.

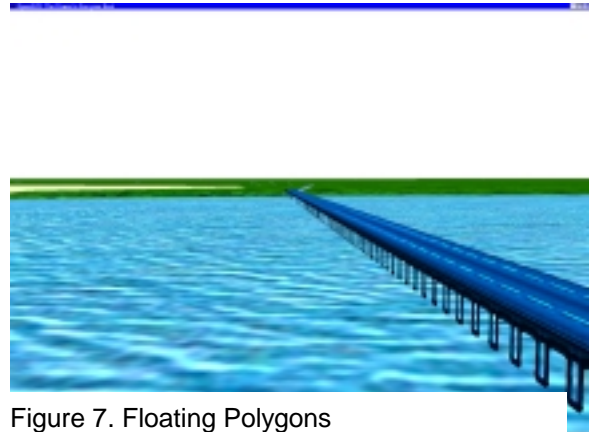


Figure 7. Floating Polygons

Another way to fix this is to find another parameter assigned to the bridge polygons that is different than terrain such as the IR material code, terrain switch, or color. Once this parameter is found, then a branch can be built under the road texture to check for the parameter, then allow the texture to float rather than be cut in. Furthermore, you could target several parameters in the same texture to attain your goal. If the texture found on the bridge were not unique then you would have to change a parameter either through the built-in vector editor in Terra Vista* or through an OpenFlight modeling tool.

External Referenced geometry in the database as a rule will only float. For instance, in the case of this database the Langley airfield was an externally referenced file. All geometry that had to be integrated (cut in) had to be copied to the appropriate flight file before importing to DART. The rule set priorities had to be set for the runways, taxiways, and runway markers in the airfield so they would be cut in correctly. Figure 8 shows these details during a landing at Langley in the final database. Buildings and distance remaining markers could stay in the externally referenced files.

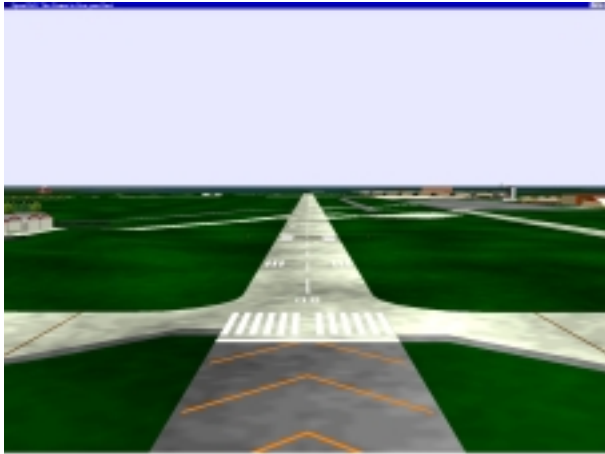


Figure 8. Runways, Taxiways, and Runway Markers

Once the rule set was defined, we then designed the LOD system. Using the DART* "Interviewer" we selected the number LODs and designated the block size of the output database. These settings control the range of the second LOD. The number of polygons assigned to the lower LOD tiles and the far clip range were also set, resulting in the desirable number of polygons over the FOV of target IG output. For example, in our design there were two LODs and the far clip range was set to 40 miles. The block size for this database equated to 20 miles range to the second LOD (TINS). This was the closest range that could be used for this database because of the maximum geometry memory available on the target machines. The view shown in Figure 9 shows a wire-frame view of the Langley airfield. If memory was not a concern this range could have been reduced to reduce the number of polygons in the field of view. Care must be taken to not over-tax the Cull process, as more flight files will be produced when the block size is reduced. Also the resolution of the lower level of detail texture mapping can be a concern with smaller block sizes. The number of polygons per FOV assigned to the lower LOD tiles was 24. This is the maximum number of polygons that DART will assign to the lower level of detail TINS. For databases that are mountainous, this setting will have to be higher for an acceptable fade in viewing in the second level of detail.

Finally, the target IG database was built over an area defined using the Thumbnail. This was especially helpful during rule design where we could define a very small area to build and quickly test the rule set. Depending on the platform it took well over 8 hours to build a 12 geo-cell database on our PC platform so most

DB builds were started for unattended over night processing.

DATABASE CONVERSION RESULTS

Excellent results were achieved for the DMT F-15C Langley as well as Eglin, Nellis, and Southwest Asia DB conversions.

The target IG platform was a dual Pentium-II 400-Mhz Windows NT 4.0 PC with 512-MB RAM and a high-end OpenGL-compliant 3-D graphics card. The maximum memory allowed for this database was 200 Mbytes geometry and 20 Mbytes texture. Although the target IG systems had 512 Mbytes of memory, we had to allow for the runtime viewer overhead (which in this case could have grown to 350 – 400 Mbytes) and other applications.

To hold the database within the geometry memory limit, we eliminated some geometry polygons in the rule set before the build. For instance, when our input (Phase 1) OpenFlight database had 3-D buildings and trees, we selectively targeted their textures and did not allow them to build into the database. When we had areals or linears that were not required, such as some roads, railroads, residential areas, etc, we eliminated those as well. However, we had to verify that appropriate geometry existed in the eliminated areas. When we encountered resulting holes in the database, we used Terra Vista* to rebuild those areas using a predefined texture map.

We had two ways of controlling texture memory size. As we reduced the block size of the database (by pulling in closer the second LOD range), our texture memory requirement increased. This is because of the "Geo-Paint" system in Terra Vista*. For every Open Flight file (. fit) in the resultant database a texture file was generated. The second possibility we exploited was to change the resolution of the texture files before the initial import. In this design the Geo-Paint texture resolution was reduced to 64 x 64 texels to accommodate the 20-Mbyte maximum texture memory. This effectively reduced the memory requirement by four from the nominal 128 x 128 Texel resolution. The resulting second LOD was then acceptable with the 20-mile range to the LOD.

The resultant OpenFlight database ran with acceptable performance at 20-25 Hz update rate over the general Langley area terrain located away from coastlines and waterways, 20 Hz in the coast line and waterway areas, and 10-20 Hz

in the Langley AFB airfield area. The airfield is complex and contains all of the 3-D buildings that existed in the original ESIG-4530GT GDF* database. Most runway markings were cut by DART* into the runway. Several airfield taxiways were modeled as smooth curved roadways that resulted in up to 12,000 polygons in the airfield area FOV and thus reduced the frame rate. In coastline areas there were up to 8,000 polygons in the FOV while 3000-5000 polygon range was prevalent. The TerraVista* *Geo-Paint** polygon-to-texture switching performed acceptably even with the reduced resolution of the texture tiles.

GDF-to-OpenFlight correlation of object shapes and locations was less than 3 meters around the airfields and less than 75 meters over areas outside the airfields (coastlines, waterways, roads, etc.).

As an example, the following figures (on the last page of the paper) visually illustrate the results of converting the Langley database from GDF* into OpenFlight. Figure 9 shows an example view of the preliminary (input) OpenFlight source. Figures 10 and 11 show the DART output correlated view to this input image. The preliminary database in Figure 9 had several layers of geometry, all linear and aerial features coplanar, with the externally referenced airfield (not shown). The final database has a single terrain skin with all features integrated into the terrain including the airfield as shown in Figure 11.

While actual DB conversion times were not of particular interest to the DMT F-15C Program, we observed that the Phase-1 plus Phase-2 conversion iterations took about two months per database and, as our experience with this conversion grew, the total time for all conversions decreased to 1.5 months average. The Eglin and Langley took more time due to working with higher polygonal shape complexity of the waterlines compared to the land-only Nellis and SW Asia areas. The actual run time to perform the Phase-2 optimization using the DART took 12 hours to process a 12-geocell, 1,200-file OpenFlight database on a 500-MHz dual-Pentium III, 512-MB, Windows NT PC.

CONCLUSIONS

The DMT F-15C Program has been using the converted Langley OpenFlight database as well as Eglin and Nellis databases with satisfactory results. The final OpenFlight database satisfied the DMT F-15C IOS, BDS, and TS desktop PC-based IG system

requirements. The issue of ESIG and OpenFlight DB correlation became visible only once - when trying to match the position of the ownership over the ESIG-4530GT OTW terrain with a less dense PC IG OpenFlight database in the IOS, BDS, and TS systems. The visually detected mis-correlation was in position over a runway and was quickly traced to a minor difference in DB offsets between the ESIG and OpenFlight DB systems; correcting the offsets eliminated the mis-correlation. Further detailed discussion of correlation issues is beyond the scope of this paper, however, it could serve as an important topic to a future "DMT F-15C Lessons Learned" session or a paper.

We have developed the basic GDF*-to-OpenFlight conversion process and optimized it four times by application to Eglin, Nellis, Southwest Asia, and Langley DMT F-15C databases. Future users, especially the US Government and Services, could benefit by converting and re-using the plethora of existing databases already developed for the large number of installed ESIG* IGs rather than developing databases 'from scratch'. Especially applications of the newly emerging PC-based IGs with lower price-performance points would greatly benefit from the relatively low cost of the conversion process and the tools used. As a final note, databases in other formats than GDF* could also be converted into OpenFlight and optimized since the heart of the final optimization step lies within the DART* tool.

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Figure 9. Preliminary Phase-1 OpenFlight Database (DART Input), Textured Polygon Wire-Frame View

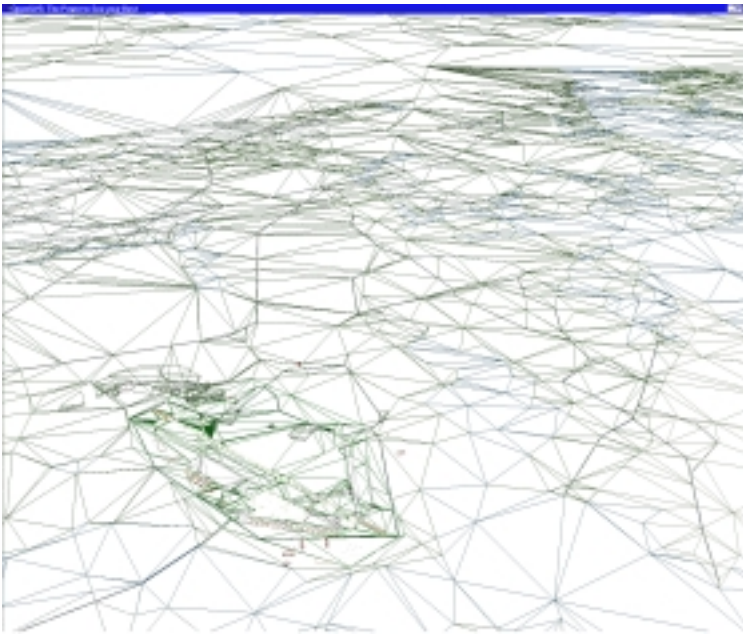


Figure 10. Phase-2 DART Output Database, Wire-Frame View

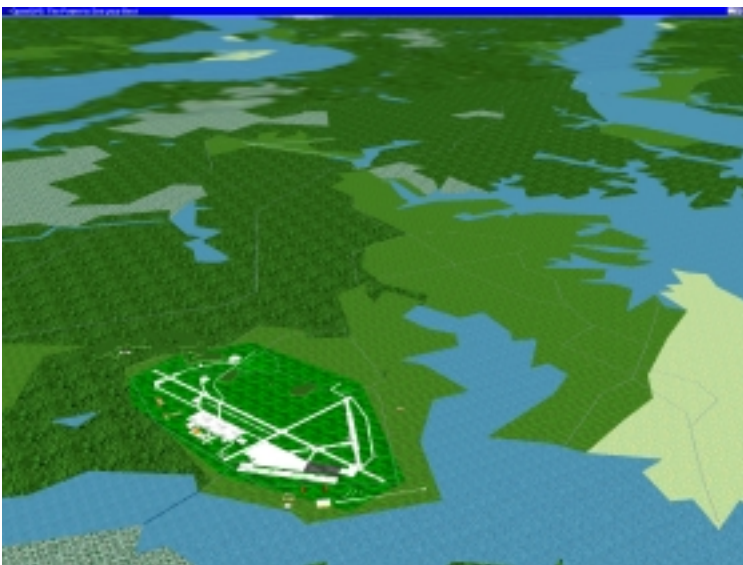


Figure 11. Phase-2 Final DART Output Database, Textured Polygon View