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THE NATIONAL GRID PROJECT: MAKING DREAMS INTO REALITY

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ABSTRACT

The National Grid Project has been under development at the NSF Engineering Research Center at Mississippi State University since 1991. A summary of the progress to date is presented. The project utilizes Non-Uniform Rational B-Splines (NURBS) for the geometry with a solid modeling Boundary Representation (B-Rep) data structure to represent topology. Geometry can be imported into the system via the Initial Graphics Exchange Specification (IGES), discrete XYZ's (interpolated into NURBS), or can be internally created by CAD operations. The NURBS are used parametrically in both the structured and unstructured grid generation. Volumetric structured and unstructured grids are generated, visualized, and evaluated within the program, allowing the user the flexibility and control of the grid generation process.

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1. INTRODUCTION

In 1991, a consortium was conviened and chartered the National Science Foundation (NSF) Engineering Research Center (ERC) at Mississippi State University (MSU) to develop a grid generation system to address the current limitations of existing systems and to expand the state-of-the-art. Joe Thompson, director of the ERC, defined the system as such:

> In 1991, the NSF Engineering Research Center at Mississippi State formed a national coalition of industrial and federal laboratory participants to develop a comprehensive grid generation system defined by users and designed by experts. ... The objective of the National Grid Project is to increase the efficiency and productivity of the grid generation process to the high-level required for high-performance computational simulation of real-world systems for design and analysis in engineering applications. ... The system incorporates a surface definition system including: an interface with IGES files and CAD systems; B-Splines and NURBS; surface-surface intersection; surface quality enhancement; a surface grid generation system based on surface parametric coordinates; a volume grid generation system including transfinite interpolation, elliptic and hyperbolic generation systems; both block-structured and unstructured grid with hybrid and chimera (overset) combinations; and orthogonal, reflective and periodic boundaries. Block interfaces and connectivity are automated and the system includes automated fault diagnostics and corrective measures[1].

The integrated system concept has been prevalent in the development of previous grid generation packages such as ICEM-CFD[2], MACGS[3], EAGLEView[4, 5], GRIDGEN[6, 7], S3D[8], and GRAPEVINE[9]. NGP will be be fully integrated through the use of the underlying database.

2. DATABASE

NGP has been developed using a solid modeling paradigm. The topology is represented by a modified Boundary Representation (B-Rep) data structure. Solid modeling topology allows multi-volume and multi-surface adjacencies to be explicitly represented[10,11]. Curves and surfaces are topologically "glued" to a specified tolerance when added into the system. All geometry is represented as Non-Uniform Rational B-Splines (NURBS).

A culmination of various CAD operations and NURBS representations in the field of Computer Aided Geometric Design (CAGD)[12-18] has been incorporated into the development of the internal CAD package. These Geometries can be imported and exported directly in the system via the use of IGES[19,20]. IGES will also serve as a common communication link between CAD packages and a mechanism to save geometry in the system. IGES will also serve as a mechanism to save the state of the user's session.

One current requirement for the grid generation is that the domains are generally four sided and one-to-one matching at the boundaries. Currently partial face matching is undetected through the topology. Facilities to prepare and repair the geometry before grid generation include uniting, splitting, and surface-surface intersection. Trimmed surfaces from IGES will be done by user intervention to guarantee four sided regions. An automated procedure is currently under investigation. Figure 1 depicts a solid model with four sided matching surfaces needed for the grid generation process.

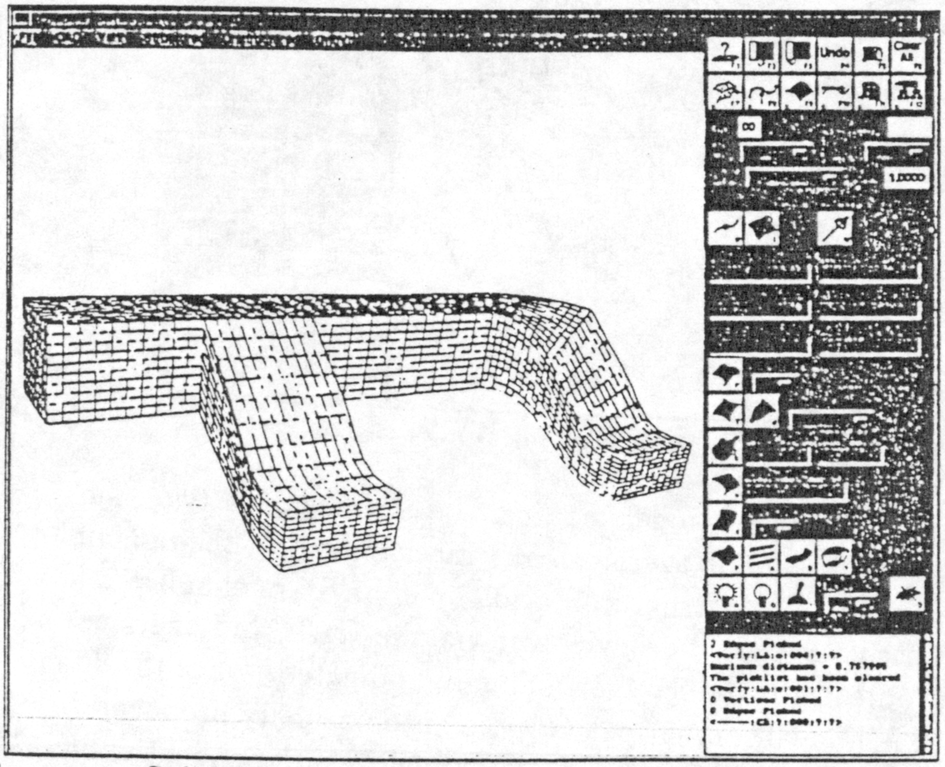

Figure 1. Solid Model of Heating/Ventilation/Air Conditioning (HVAC) Duct.

These surfaces still maybe unusable in grid generation due to edge mismatches, gaps, and/or overlaps. A surface correction module is in place that will replace selected patches of NURBS surfaces with a new NURBS surface indicated by a combination of boundary curves and/or corners. An Octree data structure[21] is implemented to speed up the search algorithm. The new NURBS surface is mapped onto the original surfaces, but is topologically independent without overlaps and gaps[22].

3. GRID GENERATION

Once the integrity of the geometry is verified, i.e. all surfaces and curves are topologically "glued", the NURBS curves and/or surfaces are used parametrically in the grid generation procedure for structured[23] and unstructured[24] discretizations.

A Deluanay technique is implemented to discretize the region into triangles and tetrahedra in cartesian space and in triangles in parametric space on surfaces. Initial clustering is governed by the boundary point distributions. User specified parameters control the density and regularity of the cells. Point sources and line sources are used to further cluster points in various regions in the unstructured method of Weatherill. The volume is generated directly from the discretized surfaces in the unstructured case. Figure 2 is the unstructured mesh of the HVAC on the given surfaces.

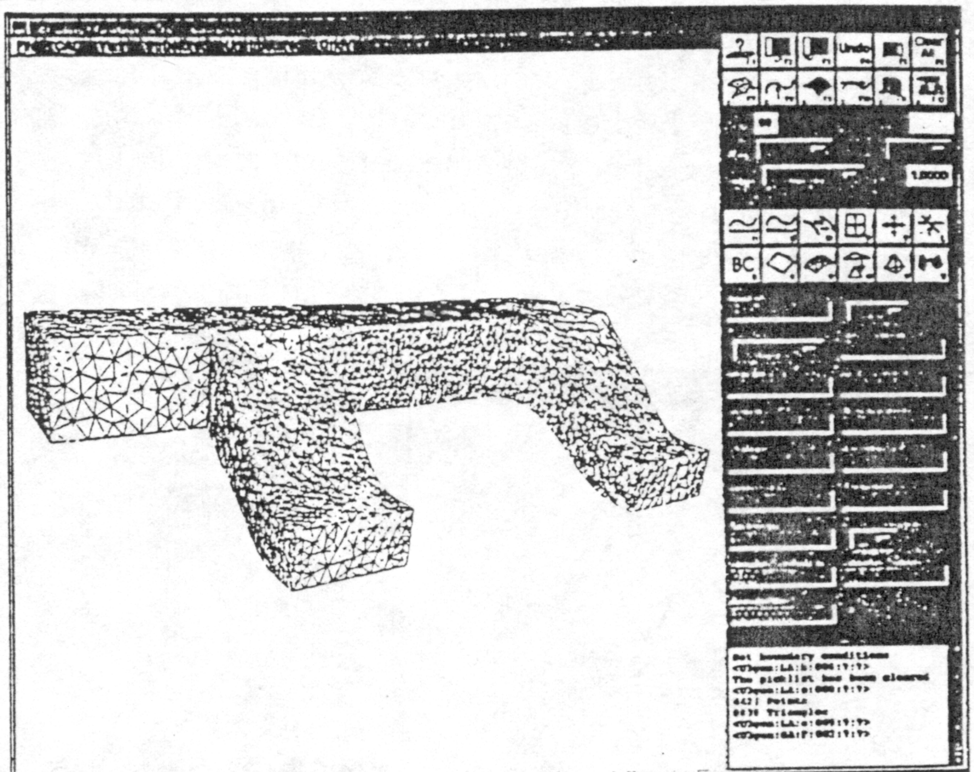

Figure 2. Unstructured grid on HVAC surfaces.

Multi-block structured grid generation can be achieved via two independent paths. One approach is the block abstraction used in the domain decomposition for multi-block structured grids by John Dannenhoffer[25]. Or, the blocking structure can be developed via the CAD and the faces and blocks are automatically detected or manually indicated. Once the domain connectivity is known, point continuity is automatically propogated to the logically oriented edges. Construction of the grid is dependent upon the visable boundaries. This allows regions to be gridded independently.

Figure 3 is the structured mesh of the HVAC on the given surfaces.

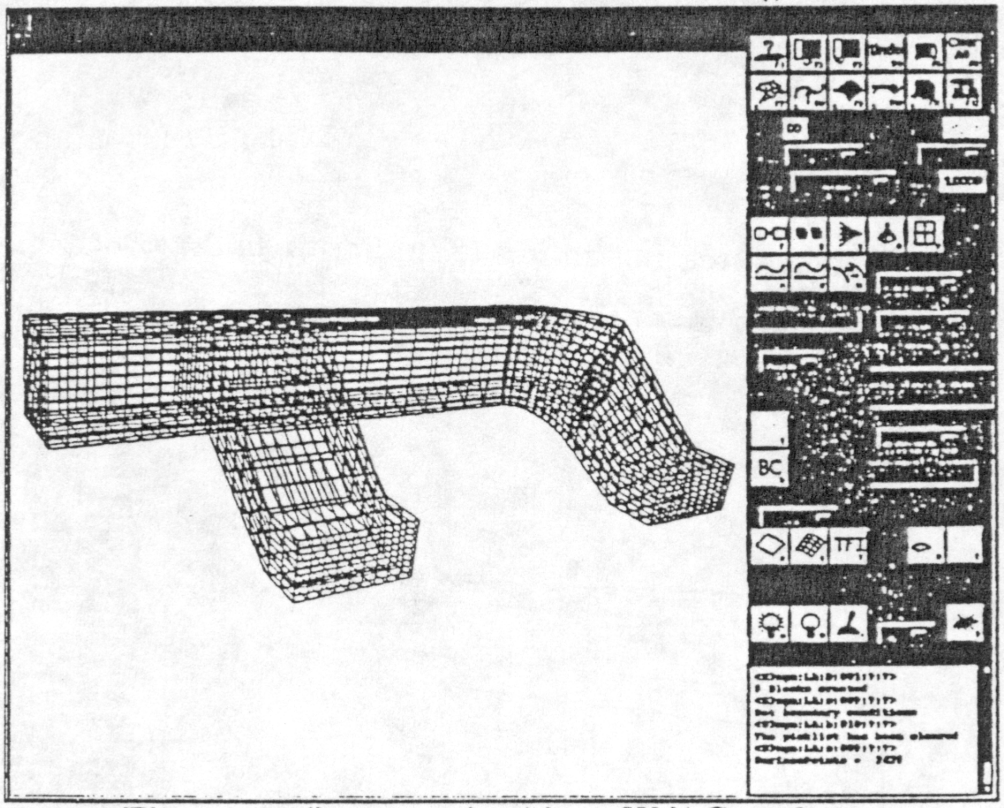

Figure 3. Structured grid on HVAC surfaces.

HYPGEN[26], the hyperbolic grid generation code developed by Joe Steger, is also incorporated to allow development of Chimera or overlapping block configurations. The grids are automatically generated normal to the indicated surface. A facility is avaible to view the surface normal and flip the direction. Currently, the block interaction is not detected, but is planned for future development.

4. GRID VISUALIZATION

New techniques for visual display of the quality of these computational grids have been developed. A visualization hierarchy of tools is developed which includes quantitative and qualitative measures as well as browsing. The qualitative tools allow the user to determine the overall quality of the grid by inspection. This is achieved by a *Cloud of Points*, where a small dot or pixel is placed on the screen to represent the grid node. This is particularly useful in visualizing unstructured grids, Figure 4. The quantitative tool is a *grid weathermap*, where node-based and cell-based grid quality measures are color coded in the configuration based on user specified limits, Figures 5 and 6 . For structured volume grids, the browsing tool allows the user to sweep constant planes, in addition to displaying the neighboring cell walls, thus creating an image similar to an "egg carton"[27], Figure 7.

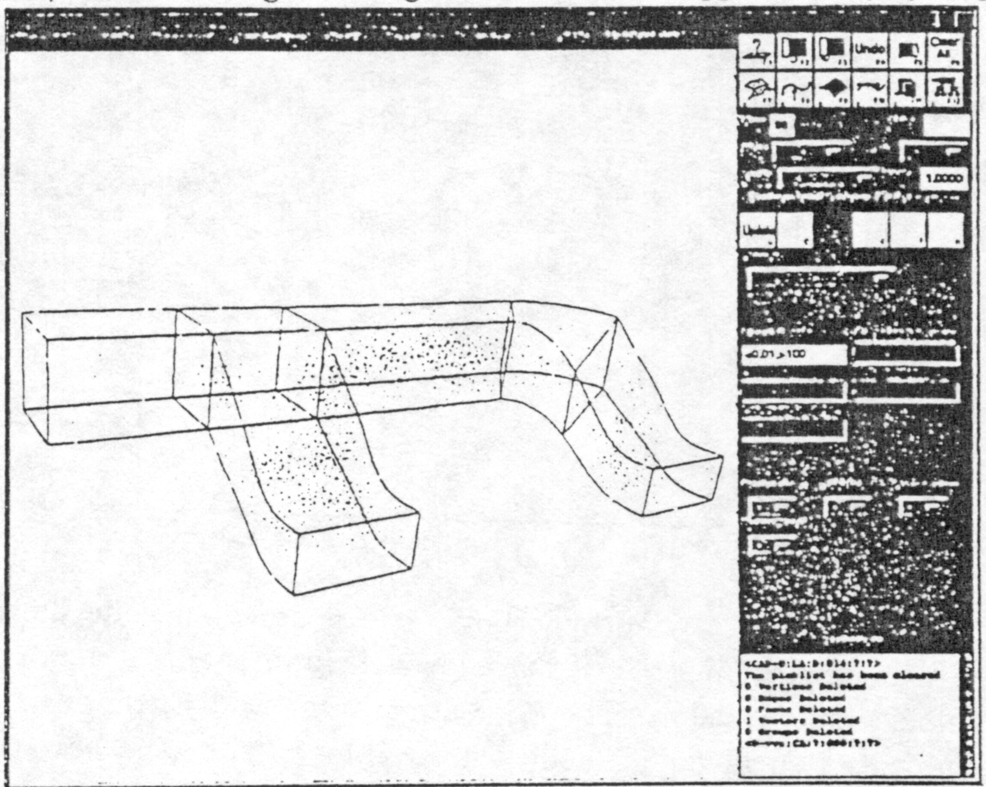

Figure 4. *Cloud of Points* of unstructured grid of HVAC.

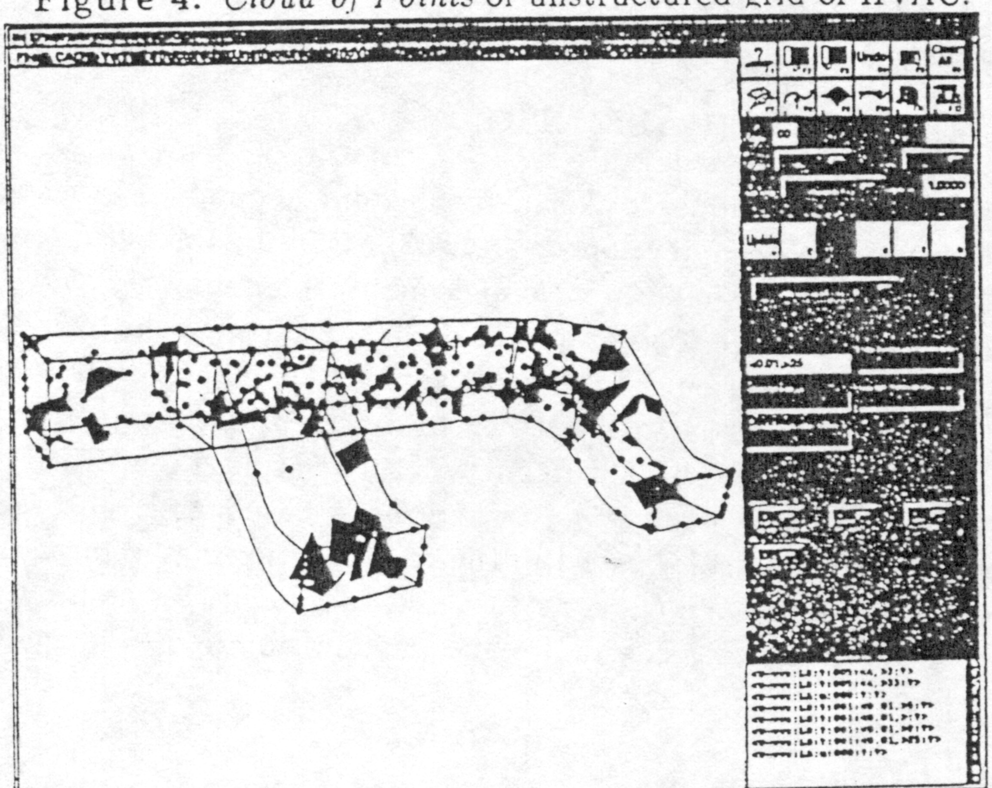

Figure 5. *Grid Weathermap* of unstructured grid of HVAC.

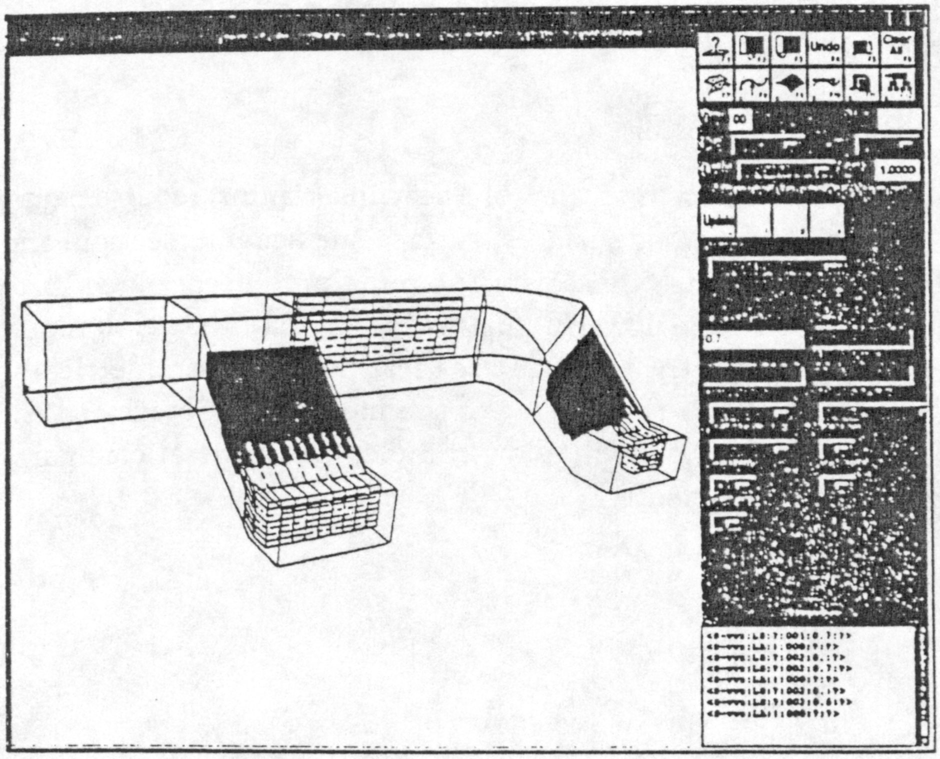

Figure 6. *Grid Weathermap* of structured grid of HVAC.

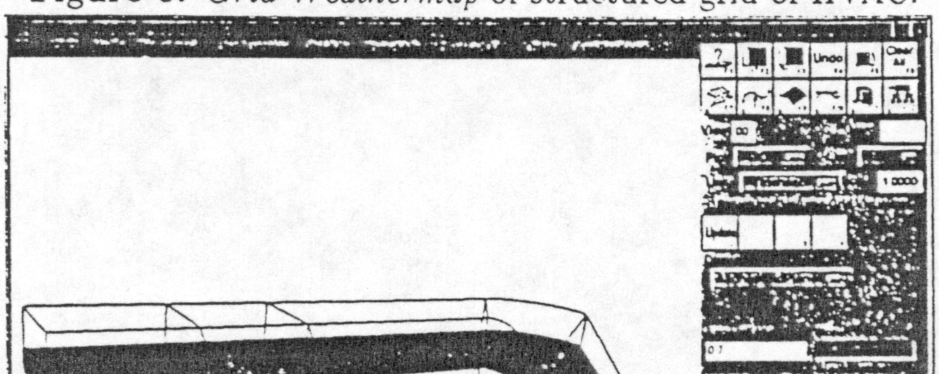

Figure 7. "Egg Carton" of structured grid of HVAC.

5. USER INTERFACE

An interactive graphical user interface is developed by using MOTIF, X, and IRIS GL. The design of the interface can be seen in the previous Figures. Graphical icons are used to represent the corresponding function attached to the button. For portability to other platforms, OpenGL™[28] will eventually be used for performing graphics. However, a script language will be developed that will have two levels of functionality: journaling geometry and grid creation and allow the use of macros to facilitate parametric studies. The current method being pursued will allow grouping and labeling of geometry and topology, by designating a set of NURBS curves and surfaces as a wing group, for instance. The leading edge and trailing edge can be designated on the topology. Conceptually, the operations will be performed on the wing and the leading or trailing edges directly by referring to them explicity by name.

6. CONCLUSION

NGP currently satisfies a majority of the consortiums requirements. Further development in trimmed surfaces, surface-surface intersection, and to allow partial face matching will satisfy the remaining needs. NGP provides grid generators with the powerful features of a CAD system to repair and construct geometry exactly, to discretize these domains parametrically, and to visualize and measure the quality of the mesh in an integrated environment. Future development will allow complex and general configurations to be grided more efficiently.

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