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Volume: AIAA-91-0800

Issue:

Date: January 1991

Author: W.K. Capron

Article Title: Advanced Aerodynamic Applications of an Interactive Geometry and Visualization System

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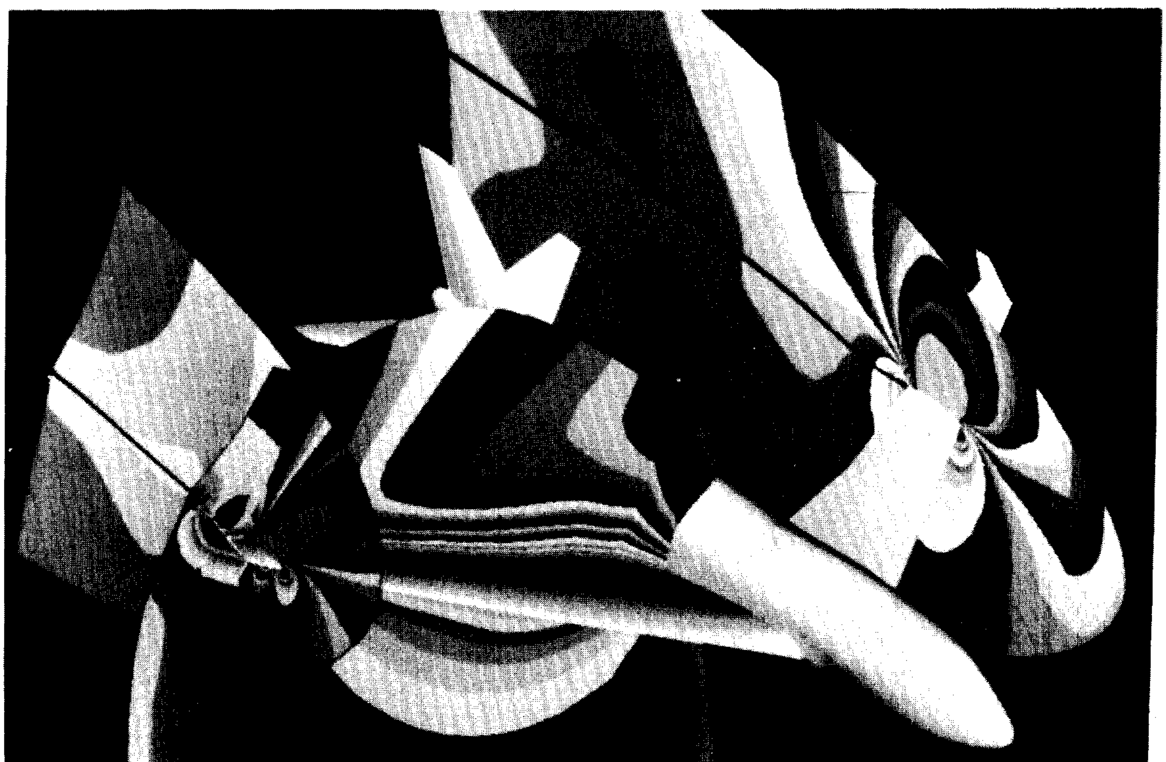
W. K. Capron and K. L. Smit
Boeing Commercial Airplane Group
Seattle, Washington , USA



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AIAA-91-0800

Advanced Aerodynamic Applications of an Interactive Geometry and Visualization System

W. K. Capron* and K. L. Smit†
Boeing Commercial Airplane Group
P.O. Box 3707, Seattle, Washington 98124, USA

This paper presents advanced aerodynamic applications of an interactive geometry and visualization system. The system, called AGPS (Aerodynamic Grid and Paneling System), is described, and its role in computational fluid dynamics (CFD) at Boeing is summarized. AGPS is used to define geometry, determine grid, and display graphics in support of CFD. Recent advances are described including developing a portable version of the code, new techniques for representing grids for CFD, and advanced graphical displays and visualization capabilities. The versatility of AGPS is highlighted by presenting a variety of nontraditional applications.

Introduction

This paper describes recent advanced applications of an interactive geometry and visualization system called the Aerodynamics Grid and Paneling System (AGPS). AGPS was developed by The Boeing Company to focus on the geometry, grid, and graphics requirements of aerodynamics engineers. It provides an effective means of interactively defining any 3D surface, extracting surface and field grids for computational fluid dynamics analysis, and visualizing numerically simulated flow fields. AGPS is extremely flexible, allowing users to do a wide variety of geometry-related tasks. In the rapidly evolving CFD environment, AGPS is able to respond to advances in techniques and algorithms. Its modular architecture and the fact that flexibility has been designed in from the very beginning have allowed it to move from supporting potential flow panel methods to handling the latest, highly sophisticated multiblock Euler and Navier-Stokes codes. The basics of AGPS have been presented previously[1] and will not be covered here.

Summary of AGPS

AGPS plays a crucial role in the computational fluid dynamics (CFD) process used at The Boeing Company; particularly in the Boeing Commercial Airplane Group.. Generally, the CFD process involves four steps (fig. 1):

- Surface definition.
- Grid generation or panel extraction.
- Flow analysis.
- Results interpretation.

AGPS (running interactively on a graphics workstation) is used effectively in every step except for the flow analysis, which requires the computational power of a supercomputer.

Surface geometry data can be obtained from external files or created within the program and then interactively modified or refined as necessary. Virtually any shape can be modeled in AGPS (fig. 2.). Surface-fitting models include cubic and quintic polynomials, rational b-splines, and transfinite interpolant and ruled surfaces, just to name a few. Surface definitions can be combined, trimmed, intersected, etc., to produce virtually any desired shape. Once a surface is defined, AGPS provides tools to carefully inspect it to verify that it has the desired characteristics. This is done by using shaded graphics, by examining curve and surface curvature displays, and by making and viewing surface extractions.

The extensive surface extraction capabilities of AGPS allow the user to prepare input to CFD codes. Surface paneling can be generated efficiently for CFD codes such as PANAIR and TRANAIR[2,3] (fig. 3). Currently, AGPS is also being used to generate surface and field grids for Euler and Navier-Stokes flow codes (fig. 4). Surface data can also be extracted for numerically controlled fabrication of parts. This method is used regularly to build wind tunnel models. Geodesic algorithms are available for filament winding.

The data visualization capabilities of AGPS allow the user to view results produced by an analysis code. These results can easily be read into AGPS in a variety of formats and displayed in color-coded form. The most common use of this by the aerodynamicist is the display of surface pressures. Different colors represent different pressure values. Hidden line and shaded graphics images can be displayed along with the flow results to produce an integrated view of the geometry, the paneling, and the analysis (fig. 5). Surface streamlines can be calculated and displayed in AGPS based on surface velocity vector information from CFD codes; also, off-body streamlines from flow codes can be displayed.

* Senior Specialist Engineer.

† Engineer. Member AIAA.

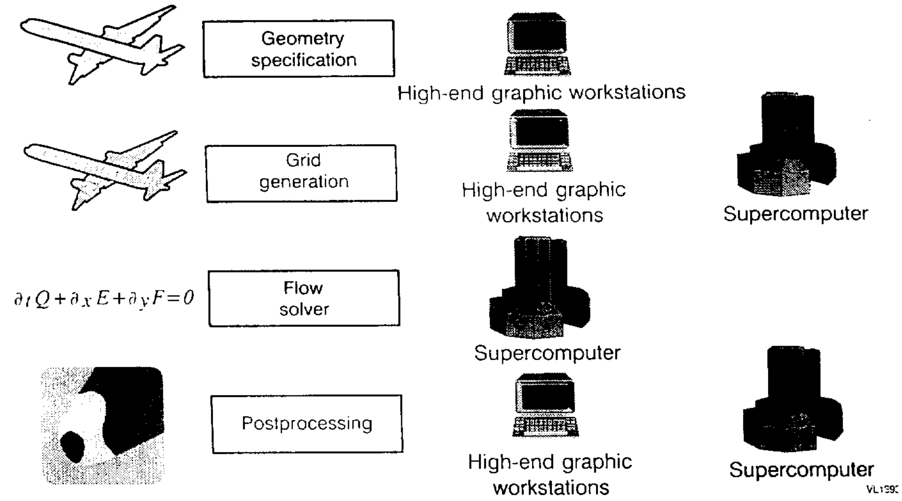


Figure 1. Four Steps of the CFD Process

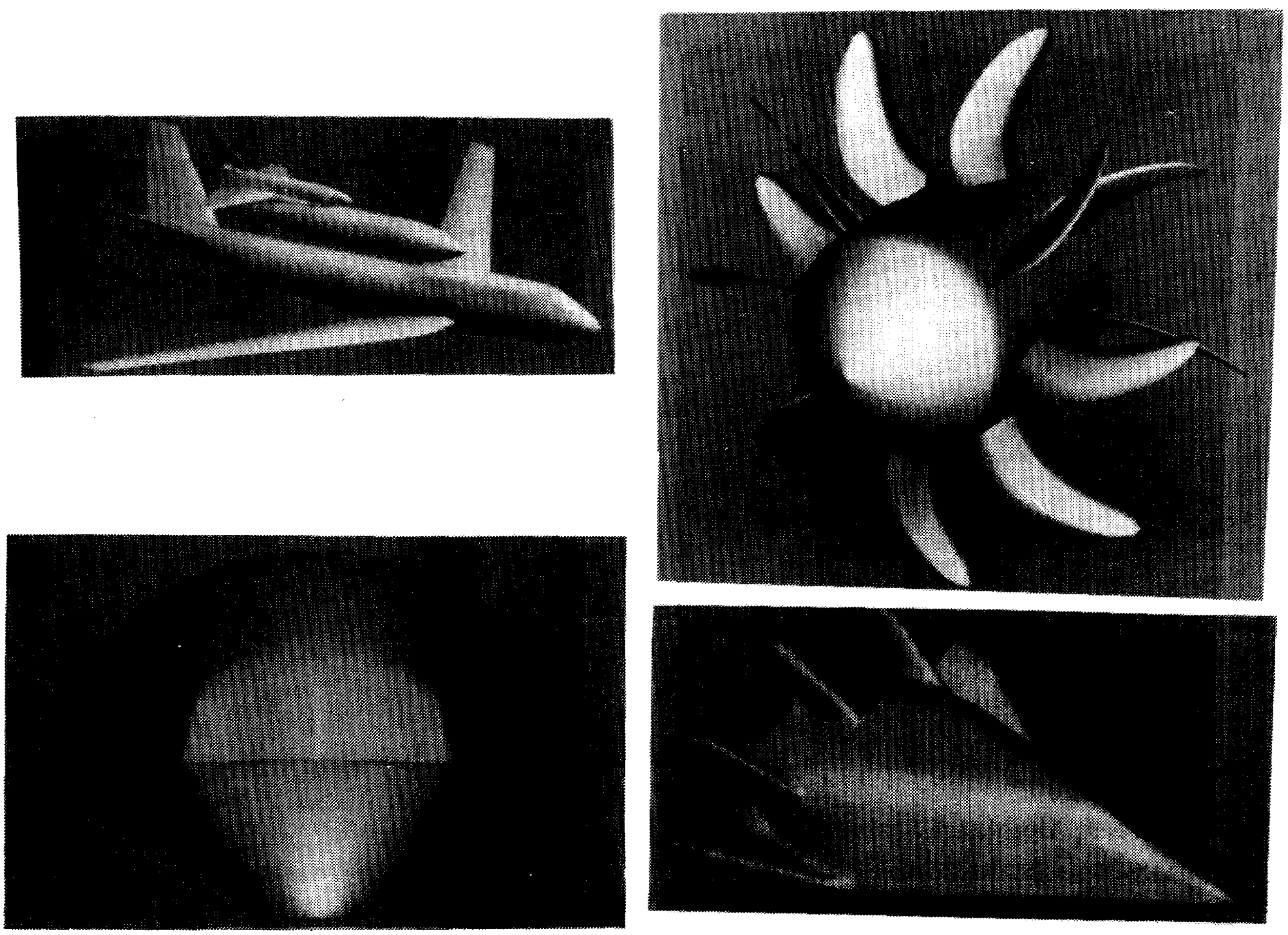


Figure 2. Representative Geometries Modeled in AGPS

AGPS can be operated from a workstation (fig. 6) in either a command-string or menu mode and from any alphanumeric terminal with access to AGPS using batch or nongraphics modes. AGPS is actually a geometry programming language rather than simply a computer program. It allows all users (not just programmers) to create macros, called command files, to repeat tasks. These command files can be made interactive, prompting the user for keyboard inputs or allowing the user to select objects from the graphics screen via the mouse. The command files can include programming constructs such as DO loops and IF-THEN-ELSE statements. Journaling (recording the steps in an interactive session) is supported; this allows for easily replaying a session with new inputs, for instance. Advanced users can easily customize the menu structure to their preferences.

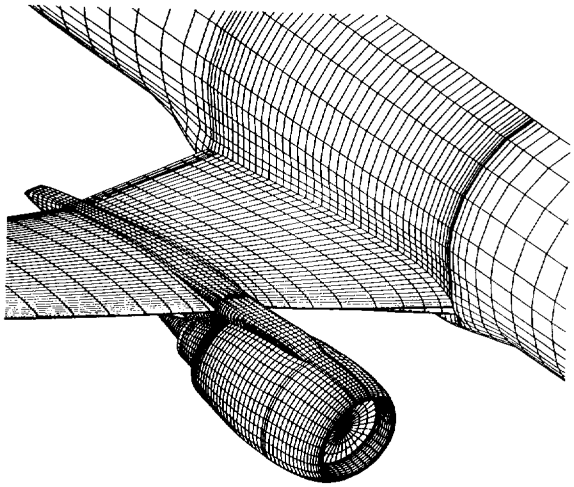


Figure 3. AGPS Surface Panels for TRANAIR

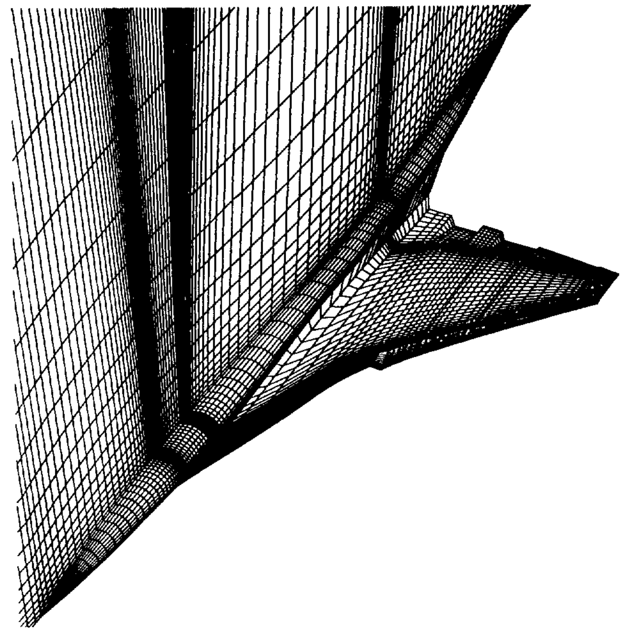


Figure 4. AGPS Surface and Field Grids for Multiblock Euler

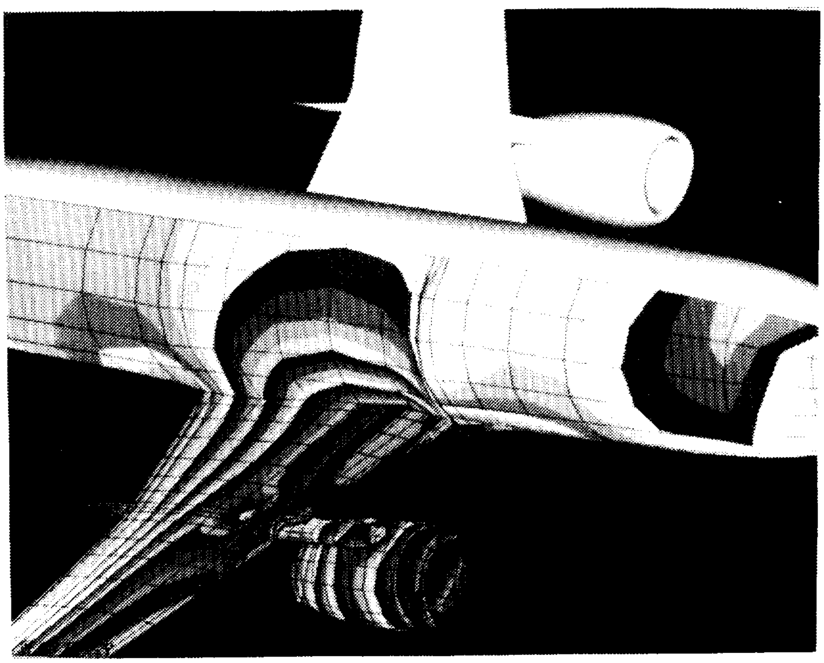


Figure 5. Integrated Shaded Graphics, Color Properties, and Hidden Lines Display

Recent Advances

Several major advances in aerodynamics applications of AGPS have taken place since the paper cited in reference 1. One major task has been rewriting AGPS so it could be ported easily to any Unix platform. The decision to convert to Unix was prompted by the desire to make the program available on a wide range of platforms. Current platforms include the Silicon Graphics IRIS 3000 and 4D series, the HP/Apollo 3000 and 4000 series, and the Digital Equipment Corporation VMS and Ultrix workstations. As new and more capable computing hardware becomes available, AGPS is well-poised to take advantage of it, regardless of the vendor. This portability makes AGPS available to a wide range of users who constantly find new and creative applications.

Currently, AGPS is being ported to the Cray Y-MP supercomputer. This will allow AGPS routines to be run on the Cray in batch mode or interactively via X-Windows from a workstation. The advantages of this include: direct linking with flow solvers for better interfacing and inverse design and solution-adaptive grid modification without losing the geometrical constraints. Having this system

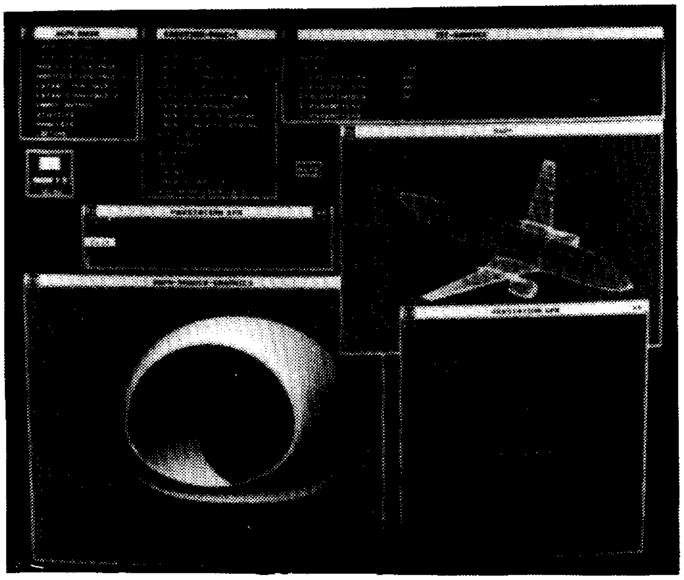


Figure 6. AGPS Operation on a Workstation

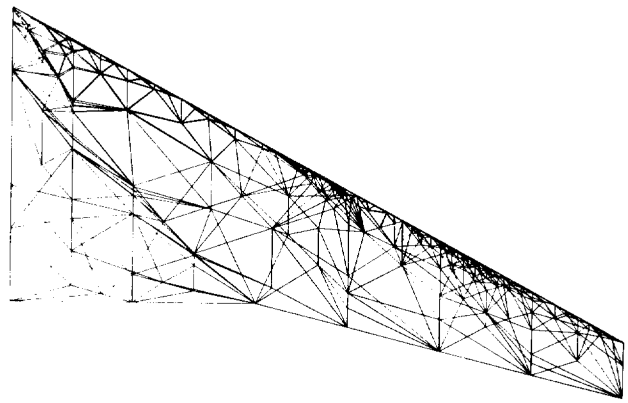


Figure 7. AGPS Unstructured Grid Prototype

available on the supercomputer has the potential of radically changing the CFD process at The Boeing Company.

A recent addition has been made to the AGPS data structure that will greatly benefit the aerodynamicist running advanced Euler and Navier-Stokes CFD codes. This unique way of storing and representing spatial coordinate data results in a two or three orders of magnitude performance improvement and greatly enhances the grid generation capability and power of AGPS. This is needed to support the large grids required by Navier-Stokes codes.

Another new addition to AGPS is unstructured grid generation. The data structure has been modified so it now can handle any unstructured form. Currently, a triangulation scheme (fig. 7) is under development to subdivide surfaces based on chord height, maximum triangle area, and maximum edge length criteria. The advantages of this approach include:

- Less memory is required by the flow solver because fewer elements are needed to define the flow region.
- There is better control of grid density.
- A given geometry definition can be modeled more accurately and in less time.

Potential drawbacks include:

- Increased memory is needed by AGPS.
- More time is required to generate and store the grid within AGPS.

High-speed workstations and the Cray Y-MP will help to alleviate these concerns.

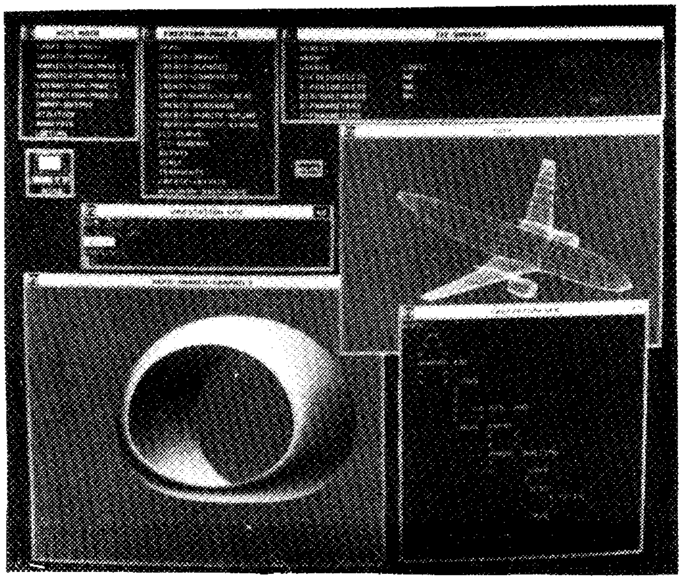
Several advances have been made in the graphics display and visualization capabilities of AGPS as well.

- Ray tracing functions have been developed (fig. 8) that include multiple point and infinite light sources, specular and diffuse surface property variation, and antialiasing for fine-tuning the image.
- Transparency has been implemented to allow viewing of the 3D flowfield surrounding an aircraft. CFD codes can provide detailed information regarding the flowfield properties. Constant values of flowfield scalar properties (such as pressure, Mach number, or temperature) can then be determined and displayed in 3D and compared with other values of the same property in the same picture by making the outer layers translucent (fig. 9), thus greatly improving interpretation and understanding of 3D flowfields.
- Extensions to current streamline calculation and solid modeling capabilities will allow generation and display of streamlines throughout the flowfield.

Innovative Applications

Grid Generation

The multiblock grid generation approach (fig. 10) at the Boeing Commercial Airplane Group is essentially a two-step process. First, AGPS is used to generate the surface, block edge, and far-field face grids. Then this information is given to the EAGLE[4] code (Eglin Arbitrary Geometry impLicit Euler, a 2D and 3D batch-mode grid generation system) to generate the volume field grids within these boundaries. Once this is done, the flow solution is computed.



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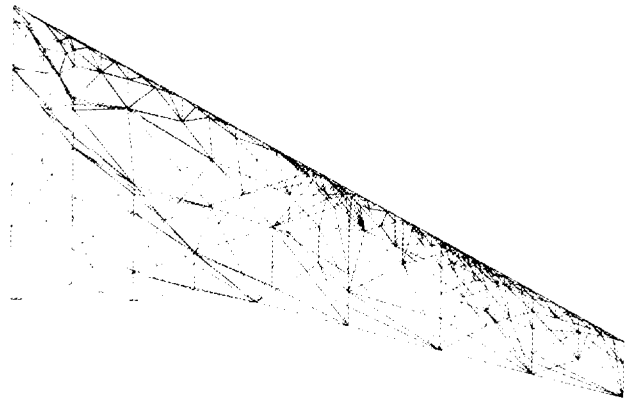

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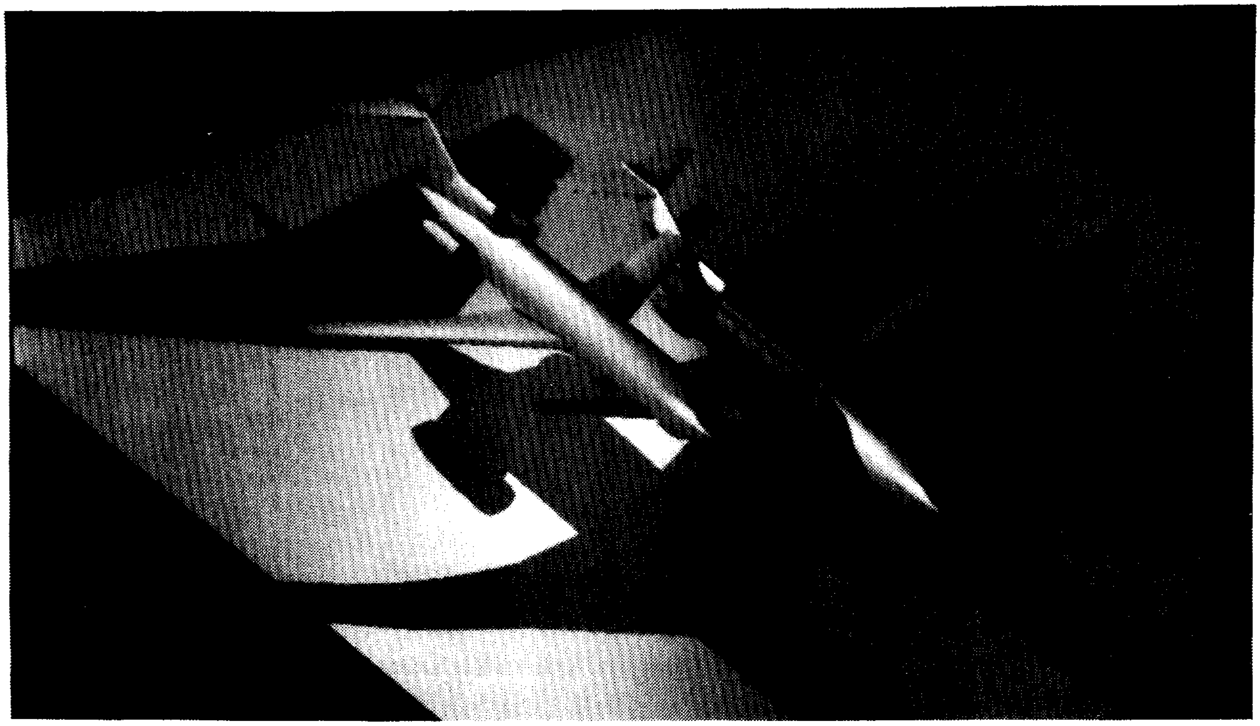

Figure 8. Ray Tracing With Multiple Light Sources

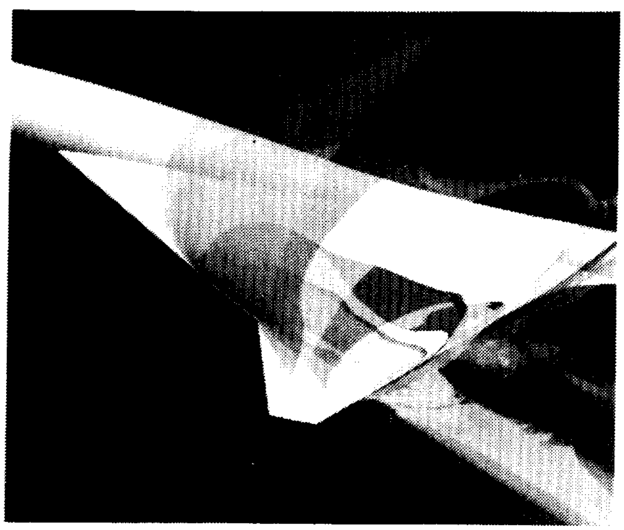

Figure 9. Field Properties Display With Transparency

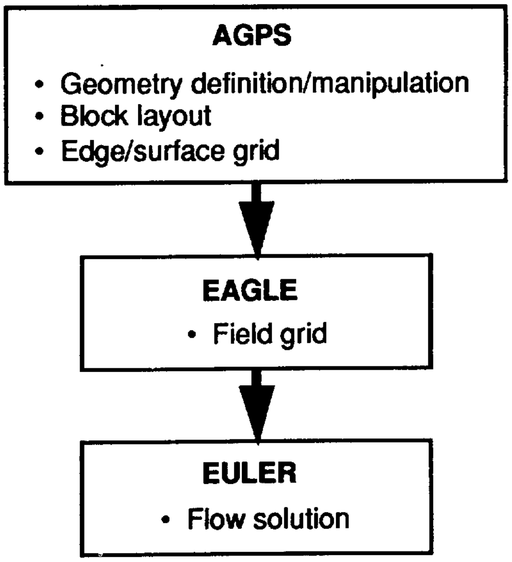

Figure 10. Current Multiblock Grid Generation Process

As additional computing power is becoming available, AGPS is being applied to field grid generation as well. It is currently being used to develop the intricate field grids required by Navier-Stokes codes to resolve boundary layer flows.

The AGPS gridding package (a collection of macros) was developed in response to an increasing need for an interactive grid generator for multiblock flow codes. A set of command files and a unique menu structure form the user interface to assist the aerodynamicist in quickly and easily creating surface, curve, edge, and face grids. The interface uses interactive graphics techniques, meaning that the objects (points, curves, surfaces, strings, and arrays of grid points) are screen-pickable with a mouse to minimize keystroke input. This package is essentially a "toolbox" of grid extraction and creation methods for generating grids to represent simple or complex configurations. Several other surface grid generation codes were examined for this job, but AGPS with its flexibility and power was found to have better surface modeling and direct point extraction capabilities than the others.

One major advantage of using AGPS for this work is that the surface grid generation is done in the same system as the surface geometry definition. When this is not the case, there is potential for error introduced through geometry transfer, surface refitting, and other approximations.

Ribbons

The Boeing Aerospace and Electronics organization is using AGPS to display "ribbon" property data along with vehicle trajectories and ground track[5]. These data, generated by a trajectory optimization program, consist of such properties as g-force, Mach number, heat loads, etc., on a vehicle along a given flightpath (fig. 11). Displayed along with the ribbon is the flight vehicle image in its proper attitude, altitude, and down-range and cross-range position. Generating this data display was originally a highly complex, time-consuming task requiring the talents of an advanced AGPS user, but now, by using the command language and a customized menu interface, inexperienced users of AGPS can display and modify this information easily by making menu picks.

Rapid Paneling of Complex Configuration

Another recent innovative application is a collection of command files that automates extraction of surface panels from a wing/body/strut/engine configuration for input to TRANAIR (see fig. 3). This relatively complex configuration, which involves many surfaces, previously took 2 to 4 weeks to properly discretize and process. Now this procedure can be done in 1 or 2 hours. Once again, AGPS was used to produce significant savings in engineering time, and it enables designers to have a far better look at the design prior to testing.

Other Applications

There has been a recent increase in nontraditional applications of AGPS as well. Other disciplines have recognized the power and flexibility of AGPS and have applied it to their surface creation, analysis, and extraction requirements. Examples of this include:

- The interface of AGPS with a load analysis program for structures.[6,7] An iterative process converges on the deflected wing shape based on the air loads from CFD and the aeroelastic wing deflections based on these loads and the structural characteristics of the wing.
- The linking of AGPS with a shot-peening code to determine wing panel shapes for manufacturing.
- Displaying aircraft geometry with lightning strike dissipation paths superimposed for avionics. This takes advantage of the capability to generate and display surface streamlines that define electromagnetic dissipation paths.
- Generating cabin interior grids to study airflow patterns for air-conditioning systems (fig. 12). The grid generated by AGPS is used by an incompressible Navier-Stokes code to find circulation of air in the cabin.

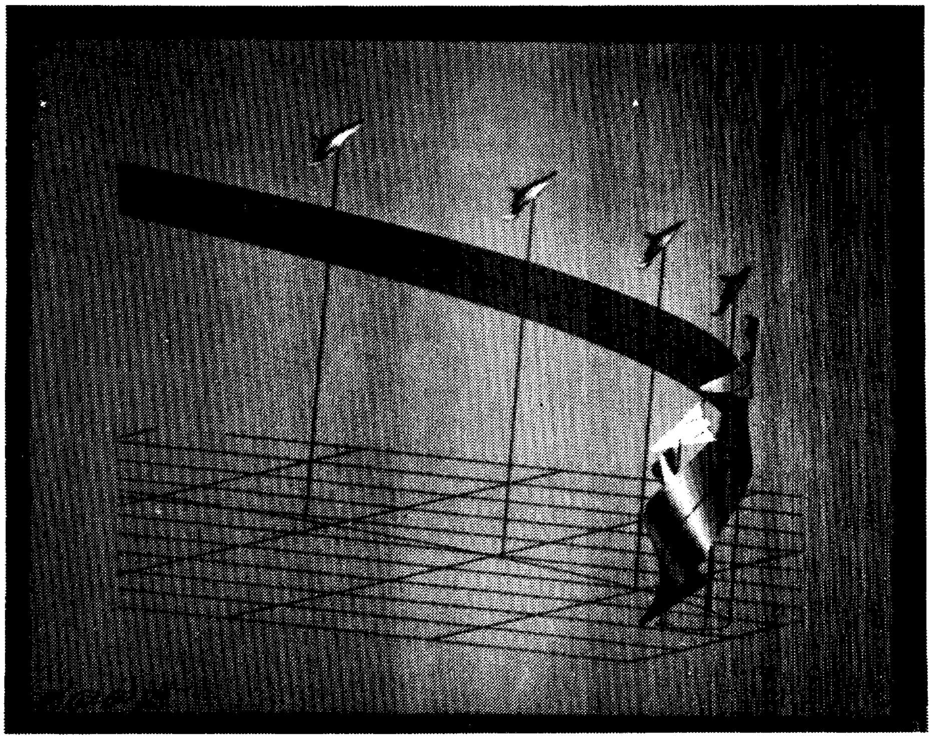

Figure 11. AGPS Display of Vehicle Trajectory Data

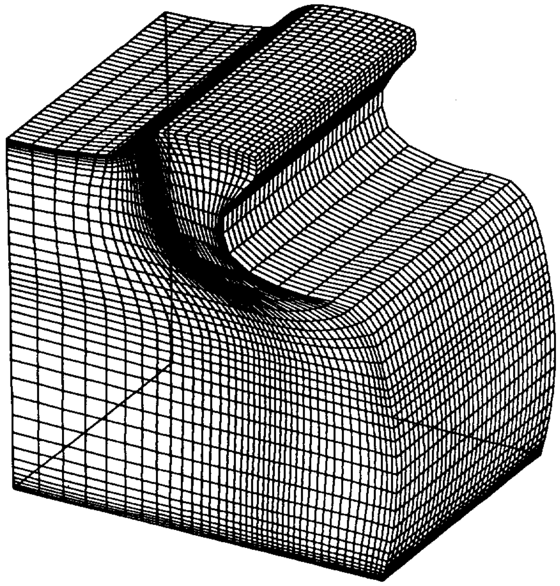

Figure 12. AGPS Grid for Cabin Airflow Analysis

Conclusions

AGPS has proven itself to be an effective and necessary tool in the aerodynamic design process at Boeing. It has always emphasized flexibility of application, and now, with the conversion to Unix, it allows flexibility in choice of the operating platform as well to take advantage of rapidly improving graphical workstations. Recent advances, such as the enhanced grid generation and transparency features, provide the aerodynamicist with much needed additional capabilities. Enhancements will continue to be implemented to accommodate the ever evolving requirements of new and enhanced CFD codes.

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