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SCIENTIFIC VISUALIZATION USING THE
FLOW ANALYSIS SOFTWARE TOOLKIT (FAST)

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ABSTRACT

Over the past few years the Flow Analysis Software Toolkit (FAST) has matured into a useful tool for visualizing and analyzing scientific data on high-performance graphics workstations. Originally designed for visualizing the results of fluid dynamics research, FAST has demonstrated its flexibility by being used in several other areas of scientific research. These research areas include earth and space sciences, acid rain and ozone modelling, and automotive design, just to name a few. This paper describes the current status of FAST, including the basic concepts, architecture, existing functionality and features, and some of the known applications for which FAST is being used. A few of the applications, by both NASA and non-NASA agencies, are outlined in more detail. Described in the outlines are the goals of each visualization project, the techniques or 'tricks' used to produce the desired results, and custom modifications to FAST, if any, done to further enhance the analysis. Some of the future directions for FAST are also described.

INTRODUCTION

With supercomputer technology advancing at a rapid pace, the amount and size of data being generated by computational researchers is becoming enormous. Tools are desperately needed to help the researchers process this data - to reduce it into manageable, understandable and useful pieces of information. For the past few years the Flow Analysis Software Toolkit (FAST) has been used by scientific researchers at NASA Ames Research Center to visually analyze their computational data. The use of FAST is becoming more widespread due to its generalized visualization approach. Originally developed for the analysis of computational fluid dynamics (CFD) results, FAST is increasingly being used by scientists to visualize data from other disciplines at research institutes across the country.

BACKGROUND

The NAS Project

In the early 1980's the Numerical Aerodynamics Simulation (NAS) project was started at NASA Ames. NAS's charter was and is to provide CFD researchers with the fastest supercomputers, the fastest networks and best support systems, including graphics workstations. On the initial NAS systems, which consisted of a CRAY 2 supercomputer, hyperchannel networks and Silicon Graphics IRIS 2000 series workstations, researchers typically generated simple 2- and 3-D volumetric data depicting fluid flow around and within solid bodies. These data sets were typically analyzed (or 'visualized') using several different software packages. In fact, the entire CFD research cycle, which includes generating the computational volume (grid), computing fluid flow characteristics within the grid, and analyzing the results, consisted of running several independent programs on both the supercomputer and workstation and moving the data files back and forth via network file transfers. This mode of operation was generally acceptable since the amount of data was fairly manageable.

The late 80's brought a new wave of supercomputers, networks and workstations that dramatically increased the amount and complexity of data being generated by researchers. It was at that time that the members of the Workstation Applications Office (WAO, part of the Fluid Dynamics division at Ames) recognized the need for a software package that could assist the researchers in all phases of the research cycle. A package was needed that was flexible, so new functionality could be added easily, consistent, so that users could learn the basics and apply that knowledge in using the rest of the package, and distributed, so that users could access and manipulate their data without having to transfer files over network lines.

Initial FAST Proposal

The WAO team proposed FAST as an 'environment' that would provide researchers with a full range of visual analysis tools, animation production capability, and the potential to monitor and/or direct their flow codes and grid generators on the fly. The target workstation was the Silicon Graphics IRIS 320 VGX - a high-performance graphics system with two processors. The original FAST design concepts were as follows:

Minimal Data Handling - Alleviate the need for the researcher to move files around.

Flexible Architecture - Implement modular design to facilitate easy addition of functionality.

Consistent User Interface - Keep the same user interface across all applications.

Highly Interactive - Provide instant feedback for each user action.

Processes Distributed to Optimal Resources - Utilize all available computing power.

The first versions of FAST achieved all of the original design goals except the distribution of processes to optimal computing resources. This capability is a planned addition to the next version of the software.

Current Status

Initial versions of FAST were released and distributed as a part of the beta test program by WAO. Currently FAST is being used at over 400 sites nationally. Development of the code is continuing under the NAS division. The latest version, which is available through COSMIC, runs on all Silicon Graphics workstations. The distribution package includes source code and a user's manual.

CURRENT ARCHITECTURE

The architecture of FAST is based on a modular design with shared memory used for storing common data. The collection of modules, each a separate UNIX process that provides a specific and independent function, makes up the FAST environment. The central module of the system is the Hub. The Hub allocates and maintains the 'pool' of data in shared memory and links all other modules to the system with two-way sockets (inter-process communication utilities). This 'hub-and-spoke' design facilitates inter-module communication as well as centralized control of the system. (See figure 1)

The remaining modules in the FAST environment are grouped into three categories: data manipulation, object manipulation and viewing. The data manipulation modules are tasked with transferring data, which typically consist of grids and flow code solutions, from the disk (or in future versions from a remote supercomputer) to core memory of the workstation. They are also responsible for computing scalar and vector quantities based on the grid and solution data. The object manipulation modules use the fundamental data to generate graphical objects such as cutting planes, isosurfaces and particle traces. The collection of these objects are then grouped, transformed and rendered to the workstation display by the viewing module which currently is the Viewer.

As stated above, this architecture fulfills all but one of the original design goals of FAST. The use of shared memory for data storage gives the user easy access to the data without having to move it from process to process. The modular design allows the system to be easily extended to include the user's own customized application. It also facilitates immediate feedback in that if the user changes a module's object the scene containing that object is

immediately updated by the Viewer. The user interface looks and feels the same in all modules so that once the user becomes familiar with basic UI concepts, learning additional components should be expedited.

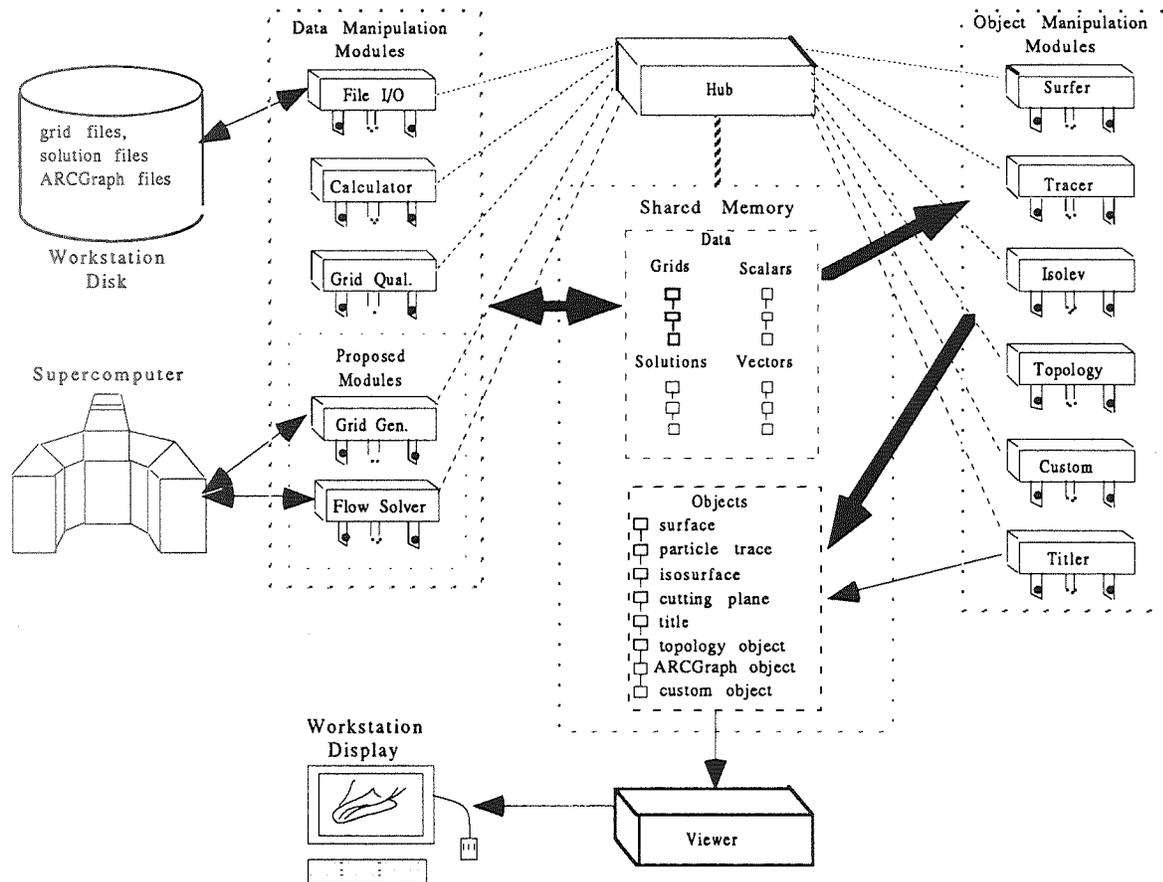


Figure 1 - FAST Architecture

CURRENT FUNCTIONALITY

In general FAST inputs grids, solutions, scalar and vector functions and creates graphical objects which are rendered to the workstation display or output to devices such as video recorders or printers. The grids describe a geometry such as an aircraft and the space around it and the solutions associate two scalar and one vector quantity with each grid node. The scalar and vector functions associate one scalar and one vector quantity with each grid node. A collection of modules operate on the data to modify it or construct graphical objects from it. The non-graphical modules make modifications to the input data which can either be written out to disk or remain in shared memory for other modules to use. The graphical modules construct graphical objects which can be interactively viewed or recorded externally to video or film media. All interaction with modules is done through a graphical user interface and each action is recorded to a script file. A FAST session can be programmed externally by constructing and executing such a script file.

Data file input and output is done with the File_io module. File_io inputs grids, solutions and function files. FAST supports all of the finite difference file formats defined by PLOT3D, an unstructured grid format developed at NASA Langley, and ARCGraph graphics metafiles. Files can be subsetted on input or output which allows for the handling of data sets too large to fit into core memory. The number of grids and solutions is limited only by the amount of core memory and swap space on the computer. All data is loaded directly into shared memory. Scalar and vector functions are loaded into registers that can be manipulated by the Calculator module.

The Calculator module operates on grids and solutions to produce scalar and vector fields that are placed in registers. The number of scalar and vector fields is limited by the number of registers (20 each) and by the amount of available

memory. There is a set of built-in CFD scalar and vector functions which are identical to the those found in PLOT3D. In addition, there is a programmable interface to the Calculator which allows users to specify formulas which apply unary and binary operators to the registers. Formulas defined by the user can be saved to and read from files.

FAST creates a variety of different surface types and rendering styles for those surfaces. The Surfer module is used to extract surfaces in computational space, which means they may or may not be planar, depending on the shape of the grid. These surfaces are planar for rectilinear data and curved for curvilinear data. Isolev, by contrast, generates either planar surfaces in physical space (cutting planes) or surfaces of constant scalar value (isosurfaces). The cutting planes can be placed at arbitrary angles to the coordinate system. Unstructured grid surfaces, cutting planes and isosurfaces can be rendered using the Surferu and Isolevu modules. All surfaces can be rendered as points, wireframe, shaded or, when displaying a scalar field, colored by a function color map. The shading and function maps can be interactively edited from the Viewer module. Vector fields can be displayed on these surfaces with or without arrowed tips. Surfaces are chosen interactively or automatically swept through the volumetric data and are illuminated by one to eight user-definable light sources.

The Tracer module in FAST is used to compute particle traces through steady state vector fields. Release points for these traces can be defined interactively and specified in either computational or physical space. Integration is either downstream, upstream or in both directions from this release point. A collection of particles (a rake) can be defined and released simultaneously. The animation of traces is used to show the dynamics of the particle paths by displaying every other integration segment (cycling) or by connecting consecutive integration segments (growing). Arbitrary scalar fields can be displayed on the particle traces by using the function color map. The Topology module also creates particle traces, but first seeks to identify critical points in the vector field by determining points where the magnitude of vector field is zero. It then classifies each critical point by analyzing the nature of the vector field in the proximity of the point, thus allowing for quick identification of interesting structures such as vortices and attachment and detachment points. Currently the particle tracing and topology features exist only for structured grids.

Traditional 2-D line plotting and text labeling is done using the Plotter and Titler modules respectively. The Plotter module can plot directly from the grid and scalar data resident in shared memory or plot coordinate pairs from an ASCII file. A variety of line styles and symbols can be applied to each plot. Multiple plots can be made on the same set of axes as to make direct comparisons of data. The Titler module provides many features to annotate a scene with scalable math and alphanumeric fonts. Text can be interactively placed in the scene or automatically aligned horizontally or vertically. Special effects like drop shadows are also available.

The Viewer module provides for the interactive viewing of the objects created by the object manipulation modules. The Viewer maintains multiple view windows and a database of scenes that can be loaded from disk or defined interactively during a session. The user is free to switch back and forth between these windows and scenes. Each view window supports full 3D interactive viewing using widget interaction, mouse or Spaceball™ input. Scenes can be antialiased and viewed in stereo using a stereo monitor. Animations can be created from these scenes and recorded frame accurately to video tape or film. FAST currently supports single frame recording to any VLAN compatible device, Abekas digital disk recorder, Lyon Lamb Minivas and Focus camera. A customizable utility is provided for recording to other devices.

Unsteady data can be visualized in FAST using the scripting language. The script file essentially runs FAST in batch mode. Objects for each time step of the visualization are created from the script, then captured on a recording device. The process is continued for each time step. A UNIX shell command feature allows for file conversions and/or network transfers after each frame is recorded.

KNOWN APPLICATIONS

The possible applications of FAST are many. The following are brief descriptions of a few of the known applications of FAST. Note that in some cases no modifications to the data or software were necessary while others required file format conversions and/or extensions to FAST.

Aerospace

FAST is used by researchers at NASA Ames and other aerospace agencies to analyze computed fluid flow around aircraft to determine the flight properties of the vehicles. Researchers use FAST as a part of their daily analysis of CFD results as well as for high-quality production of still pictures and videos for their publications and presentations.

Since FAST was originally developed for use by the aerospace community, its available visualization techniques are directly applicable. Scalar-mapped surfaces are typically used to show properties such as pressure or temperature on vehicle surfaces as well as in the free stream. Velocity vectors and particle traces indicate air flow patterns such as vortices and re-circulation regions. Other areas of interesting flow characteristics can be displayed using isosurfaces and topology extraction. Isosurfaces are used to isolate boundaries of flow characteristics. Topology extraction is used to isolate critical points in the flow field such as vortex cores and flow separation points.

Since FAST is tailored to aerospace applications there are typically little or no modifications to files or software required. Some examples of aerospace applications are shown in figures 2 and 3.

Automotive

Ford Motor Company uses FAST in their design process to investigate various characteristics around and within automobiles. Proposed designs are run through analysis codes which compute properties such as air flow and temperature distribution. The designs are potentially modified based on the results of the analysis. FAST is used to visualize the results of the analysis codes to simplify the design evaluation process.

A recent gas tank study demonstrates FAST's ability to handle both structured and unstructured data simultaneously. First, the exterior body and engine compartment were modeled using structured grids. The computed structured solution sets were then used as inlet conditions to a highly accurate unstructured model of the underbody region with emphasis on the gas tank. Using FAST, the Ford researchers were able to visually inspect and analyze their data at the points where the structured domain lined up with the unstructured regions. They were able to show the correlation between the computed results and the test data, which compared quite favorably. The visual interface that FAST offered the scientists (both in the pre-processing and post-processing phases) was most effective and essential to the analysis.

Ford's applications are possible after a few modifications. Since Ford's unstructured data format is different than that handled by FAST, a module was developed that reads the unstructured data from disk and allows the user to select the component(s) to be displayed. Ford's fluid flow data is structured in nature but not in PLOT3D format. Modifications were made to the custom module to process this alternative format. Examples of Ford's applications are shown in figure 4.

Environmental

Researchers at the National Data Processing Division (NDPD) of the U.S. Environmental Protection Agency are using FAST in several ways to visualize their computational and experimental data. Acid rain and ozone depletion models are compiled at the NDPD representing days, weeks and even years of atmospheric properties over certain regions of the U.S. These models, which are based on past history but will eventually be used to help predict atmospheric behavior, indicate definite patterns in air pollution and acid rain distribution related to weather, topology and other factors.

To visualize the acid rain models FAST is used by animating a time series of a single slice of the model representing a constant altitude level. The property being investigated is plotted on the plane as color with high values, or concentrations, of the property in bright colors and low values in darker colors. The values are sometimes accentuated by raising the points off the plane in proportion to the magnitude of the property value, thus giving the plane a relief map look. This technique makes high values easily recognizable since they are displayed as brightly colored peaks in the plot. The plots are typically animated over time with a geographical reference (eg. state outlines) and sometimes with corresponding velocity vectors representing wind direction and magnitude. The researchers will often animate the plots of one property next to another to show the correlation of the two. For

example, a time series of the occurrence of acid rain, can be displayed next to the corresponding displays of precipitation and air pollution concentration. This clearly shows that there is a correlation between the presence of both high concentrations of air pollution and precipitation with the occurrence of acid rain.

Another application of FAST at the EPA is the visualization of the changing ozone hole over the south pole. In this time series the ozone concentration levels are plotted as described above using color and height to represent the different levels. The result is a dramatic series of images showing the development of a large region of low values, or a hole, in ozone concentration. As the series, or time, continues, the hole disappears and redevelops periodically.

These visualizations were possible after converting the data files to PLOT3D format. Time-dependent data was animated by looping through sequences of 2-D planes using the Surfer module. Examples of EPA applications are shown in figure 5.

Earth/Space Sciences

At NASA Goddard Space Flight Center FAST is used by earth and space scientists to analyze their research data. In particular it was used to visualize the results of a study done on the topology of the earth's magnetosphere. In this case the researcher was interested in the effects of the interplanetary magnetic field, solar wind and ionosphere on the magnetosphere.

The interesting aspect of this visualization was the use of the particle tracing capability in FAST to identify the magnetic field lines around the earth. The general nature of the tracing algorithm allowed for the traces to be computed through the magnetic field rather than a velocity field as is typically done in aerospace applications. The path lines clearly showed the topology of the magnetic field and the general geometry of the magnetosphere. A shaded sphere representing the earth was accurately positioned in the scene to provide a frame of reference for the data.

This visualization required no modification to FAST. The data was already in the proper format since the researcher had used PLOT3D in the past. An image displaying the magnetosphere data is shown in figure 6.

Metallurgy

Research is done at Metalworking Technology to determine injection mold designs that promote even cooling of the injected material. The data from the analysis codes are a time series representing the cooling of the material in the mold. The visualization of the data with FAST allowed the researchers to easily identify areas of faster or slower cooling.

The data was in the form of a rectangular volume with geometry and temperature information at each node (as opposed to typical CFD data in which the geometry is defined by the grid). Because of this there was no way to directly identify and render the inner surface of the mold. The data was slightly modified to facilitate the generation of an isosurface that represented the inner mold. Temperature-mapped cutting planes were used to show the cooling on the inside of the mold. The temperature data on the plane was animated over time to effectively show the general cooling patterns in the mold.

As stated above, this visualization was done with minimal data file format conversion but no software modification. A single frame of the time-series is shown in figure 7.

FUTURE DIRECTIONS

Currently there are several enhancements planned for the FAST environment. The user interface will be modified to be more programmable and utilize a standard mechanism such as Motif. This change should make FAST easier to use and more portable to other workstation platforms. Modifications will be made to allow for the distribution of modules to alternate (remote) computers. This capability will allow the user to get the most out of his or her available computing environment. It should also facilitate the graphical 'tracking' and 'steering' of computational research codes running on remote supercomputers. Modifications will also be made so that the addition of modules to the FAST environment will be easier. A programmer's guide will be produced to further simplify this process. Other enhancements will include increased unstructured data visualization capability and improved unsteady, or time-dependent, data visualization.

CONCLUSIONS

It has been shown that FAST can be effective in visualizing data from several different research disciplines. With FAST being used at over 400 sites across the country there are most likely many more applications that the authors are not aware of. In the future, FAST should continue to mature as a flexible yet powerful visualization tool so that scientists in a wide variety of research areas can use it to enhance their productivity.

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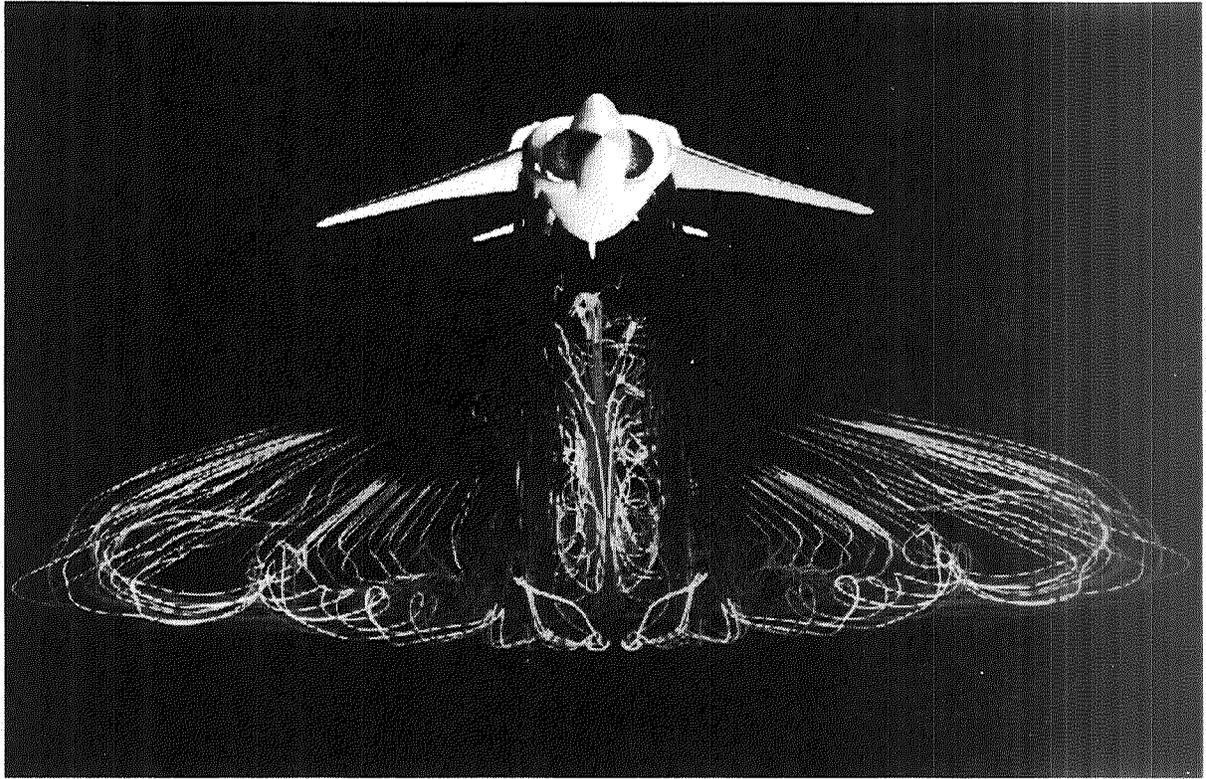


Figure 2: Harrier Jet - Data from NASA Ames Research Center

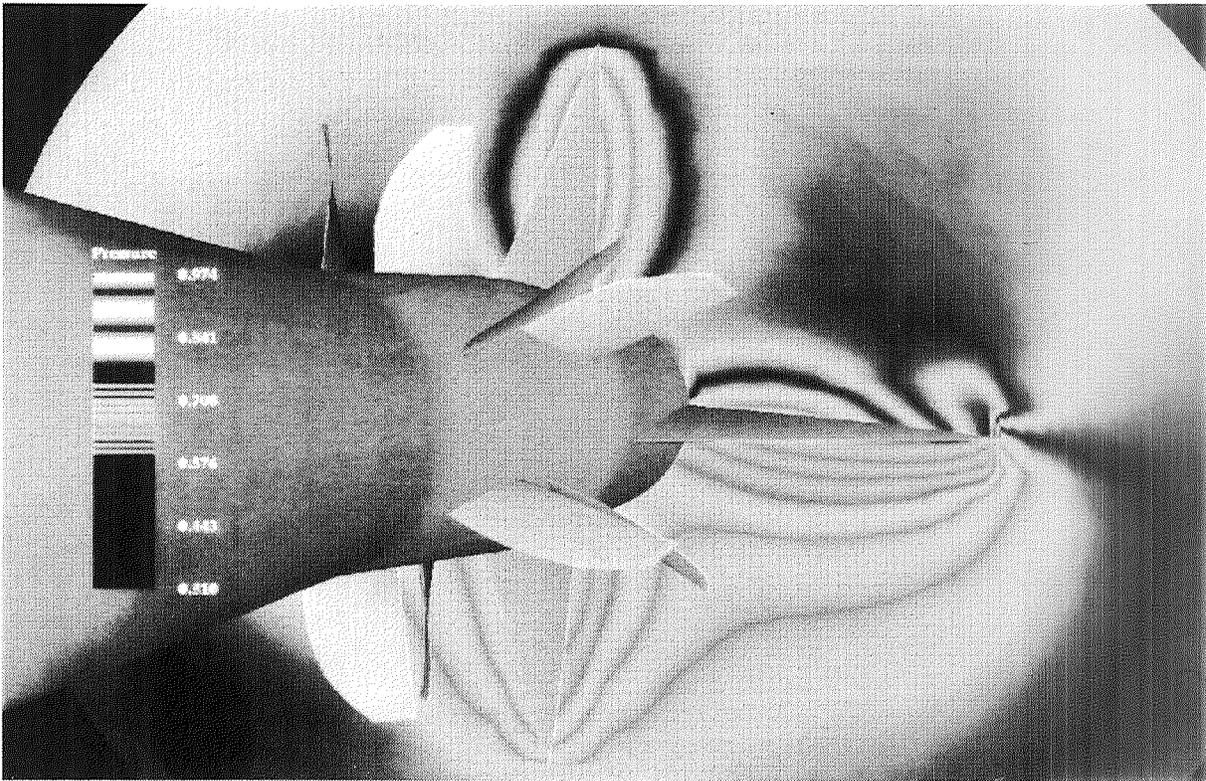


Figure 3: Cruise Missile - Data from Mississippi State University

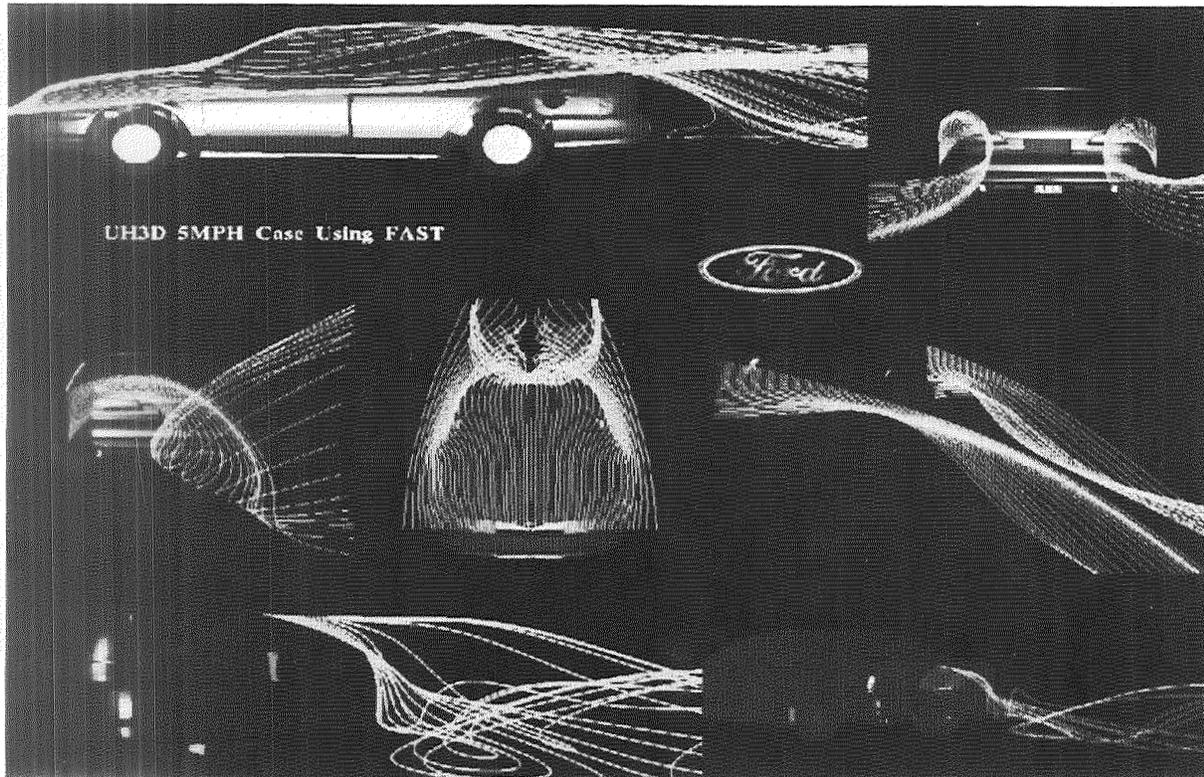


Figure 4: Taurus - Data from Ford Motor Company

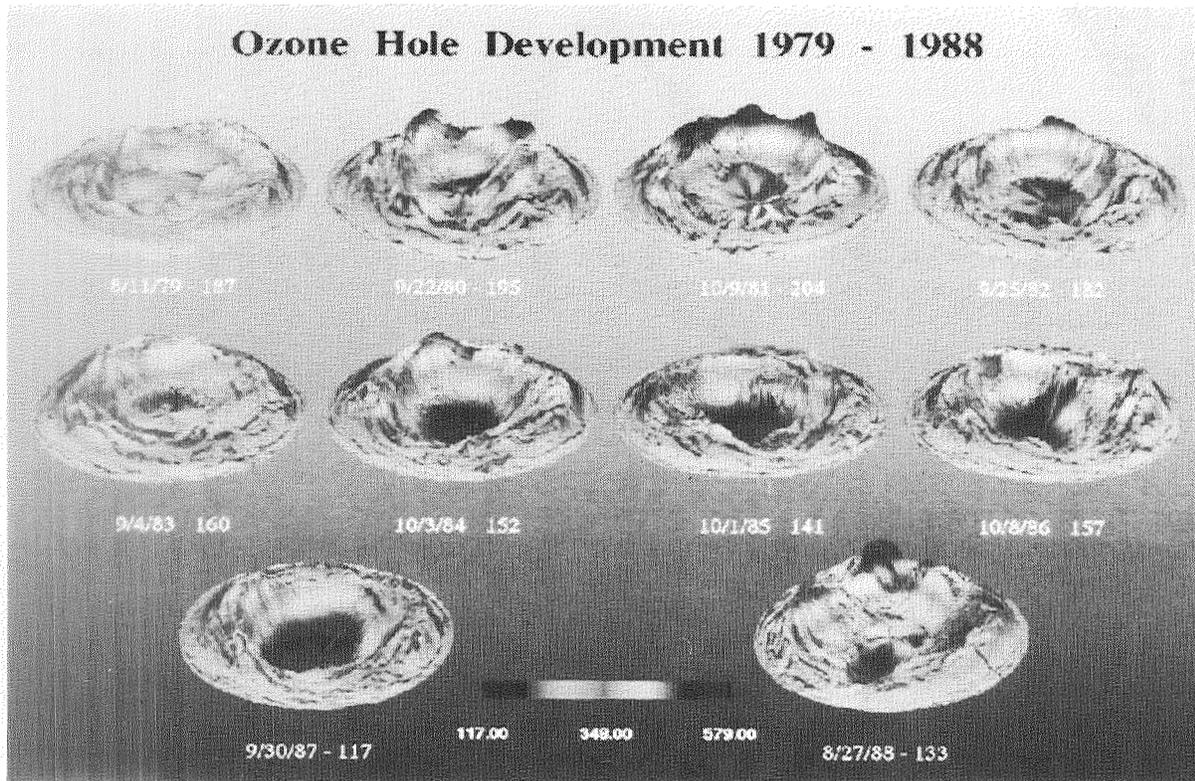


Figure 5: Ozone Hole - Data from the U.S. Environmental Protection Agency

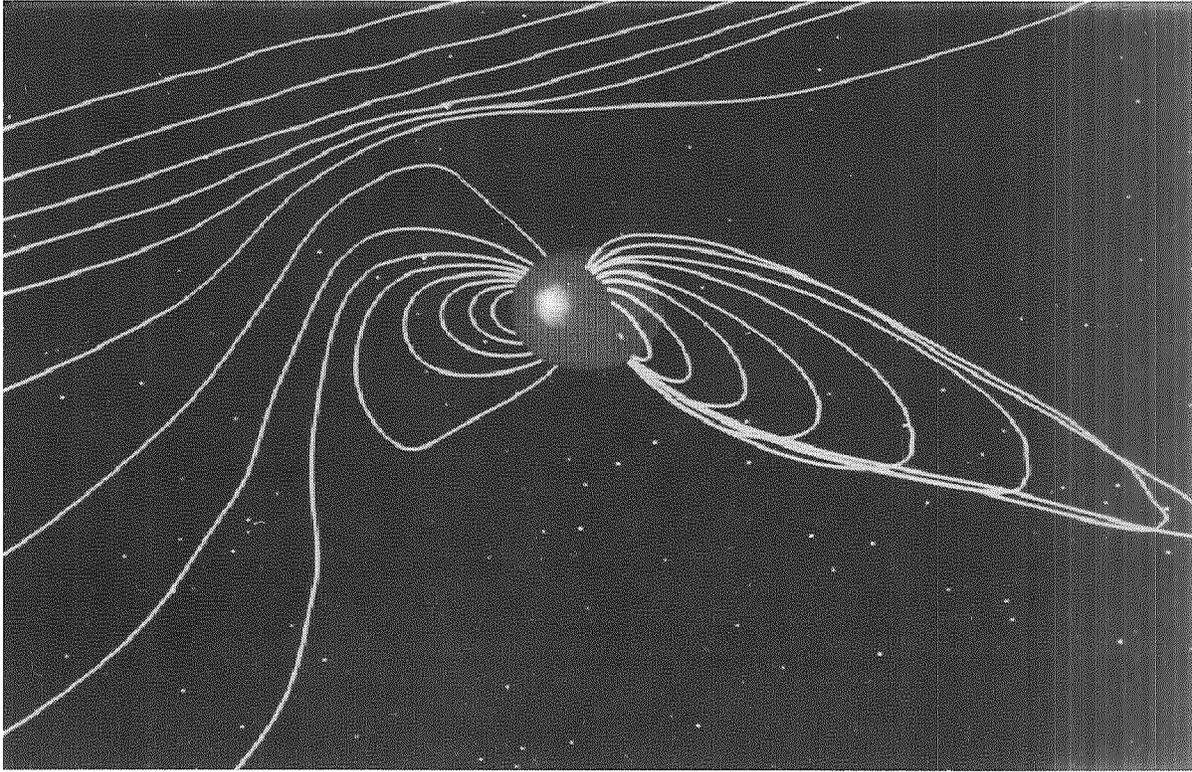


Figure 6: Earth Magnetosphere - Data from NASA Goddard Space Flight Center

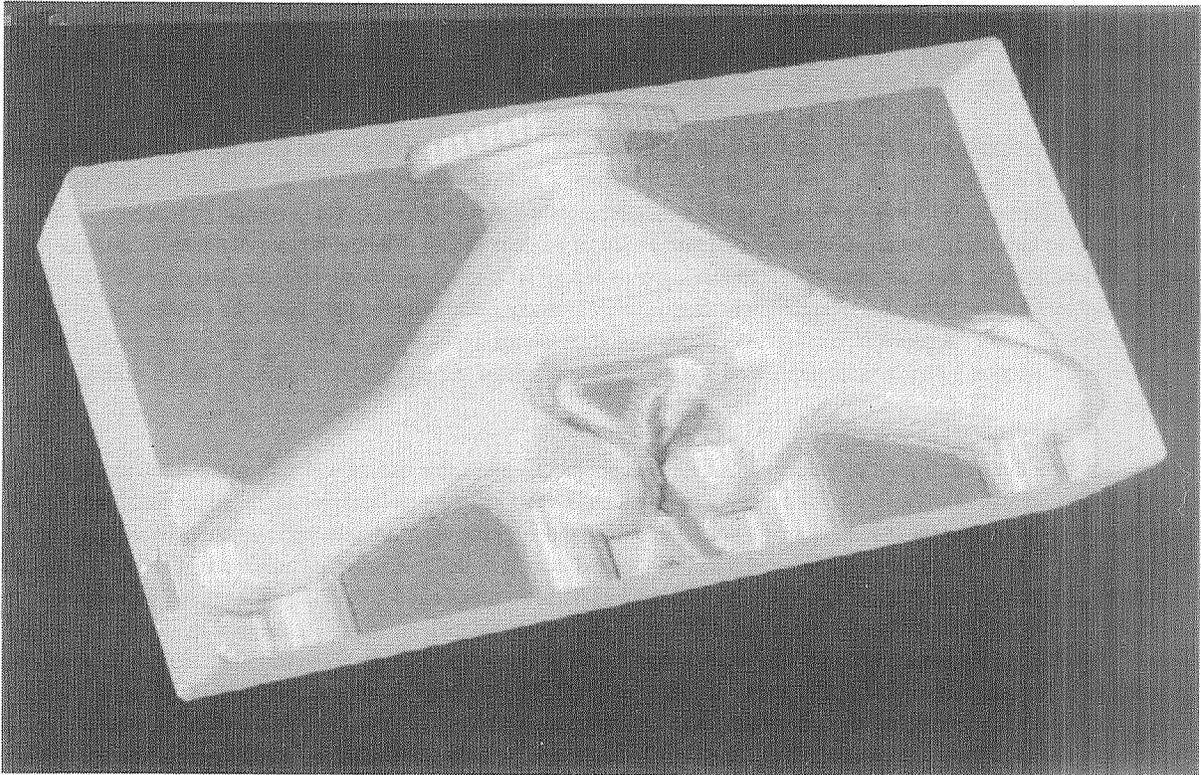


Figure 7: Injection Mold - Data from Metalworking Technology Incorporated