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Computer Graphics Display Technique for the Examination of Aircraft Design Data

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An interactive computer graphics technique has been developed for quickly sorting and interpreting large amounts of aerodynamic data. It utilizes a graphic representation rather than numbers. The geometry package represents the vehicle as a set of panels. These panels are ordered in groups of ascending values (e.g., equilibrium temperatures). The groups are then displayed successively on a CRT building up to the complete vehicle. A zoom feature allows for displaying only the panels with values between certain limits. The addition of color allows a one-time display, thus eliminating the need for a display buildup.

Introduction

MODERN aircraft design commonly involves the use of high-speed computers to generate preliminary design data. These rapid calculations have greatly reduced the time needed to reiterate the conceptual design in an effort to maximize performance before beginning the detailed design of a selected configuration. In most cases, early changes to either the configuration geometry or to the preliminary design information are based on the total integrated aerodynamic data over the entire configuration. However, even in preliminary analysis there are areas that require an in-depth examination of the individual nonintegrated values. For example, to initially lay out the structure for high-speed aircraft, a knowledge of the typical load and heating distributions is required. This will be used to make a first cut at the stress levels, select and size the surface material, and lay out the load bearing members. Usually to accomplish this task the designer must sit down and go through stacks of computer output and pick out the necessary details. Owing to the shear mass of theoretical data available, this will not be done at each step in the early design and will, of course, limit the tradeoffs that can be made.

Therefore, in response to a need for a quick efficient means of sorting through the data, an interactive computer-generated graphics display method has been developed and will be described in this paper.

Computer-Aided Design System

The Performance Aerodynamics Branch at the NASA Langley Research Center has been using computer graphics for preliminary design and analysis of aircraft and missile concepts for the past several years. It was during this time frame that a computer-aided design system was developed specifically for the use of our small research group, which is composed primarily of researchers, not programmers. The details of this system and its development are contained in Ref. 1. Specifically, the goals of this system were to: 1) provide a means for rapid geometry definition and verification; 2) arrange this geometry into a format specified by one of the several aerodynamic analysis codes and then perform the analysis; and 3) provide a means for interrogation and examination of the results of the analysis. The resulting system is known as the ACTION system.

Figure 1 contains a flow chart describing how the ACTION system operates. The ACTION program operates in a distributed processing mode which consists of a Prime 750 minicomputer tied to a CDC 6600 computer via a communication link. The minicomputer is assigned the tasks, like graphics, which require speed and response time as opposed to accuracy and storage (memory). The large mainframe computer is reserved for running the aerodynamic analysis codes where storage and compute time are large, which would place impossible demands on the minicomputer.

A typical session at an ACTION terminal begins with the input of the geometry, usually via a graphics tablet. Many of the analysis techniques rely on an accurate geometric representation of the configuration. This is satisfied by use of GEMPAK (Ref. 2), an arbitrary aircraft geometry generator which is part of the ACTION system. The vehicle under analysis is represented as a set of panels as shown in Fig. 2.

Once the geometry is input it can be checked and verified before being sent to the mainframe computer for analysis. The results of the analysis usually consists of two parts. The first part contains the total integrated aerodynamic data and the second part contains the detailed panel calculations (nonintegrated). The integrated data are returned to the minicomputer via the communication link for interrogation by the ACTION user. Typical aerodynamic plots of coefficient data may be obtained at the CRT screen and usually are used to decide on changes to the configuration.

The detailed panel calculations are not returned to the minicomputer because of the shear volume of the data. This information, if desired, can be output to a line printer and usually results in a substantial computer printout. For some design purposes the detailed information may be the major

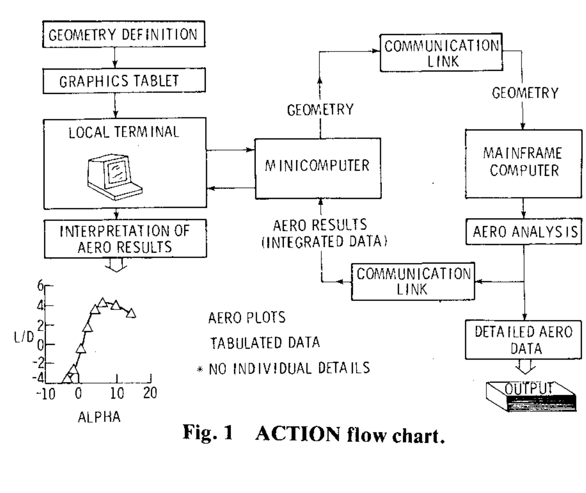

Fig. 1 ACTION flow chart.

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item of interest and some means is needed for rapid examination of this information. To meet this need, a program was initiated to develop a technique for the graphic display of large amounts of data which would become a part of the ACTION conceptual design system.

Graphic Display of Aerodynamic Data

The initial step in the development of a data analysis technique was to see that the detailed aerodynamic data calculated on the mainframe computer were stored on a file and shipped back to the minicomputer. This was accomplished by modifying the analysis code to output the information to the file in question. Next, a method of graphically displaying this information was needed. Several ideas were examined to find the best method.

The first idea that comes to mind would be to write the calculated value on the panel itself. Then the data distribution would be immediately obvious. However, this method will not work when dealing with the complex configurations like the one shown in Fig. 2. Many of the panels are quite small and would have to be enlarged before information could be written within the lines defining their edges. This would entail enlarging portions of the vehicle before the logic could be developed to write the calculated values on the panels. Because of the complexity involved, this approach was abandoned.

A second method examined involved drawing the configuration on the CRT screen in such a manner that the distribution could be discerned. Figure 3 shows an attempt to create a shading of the panels which would correlate with the calculated value. Unfortunately, the logic employed produced the results shown, which was soon dubbed the "cast iron" look. It was decided that this method could not be improved enough to function on a monochrome monitor (green-on-green).

Finally a set of guidelines were established which would eventually lead to the display method now in use: 1) the Graphic Data Display (GDD) technique would utilize the one-to-one relationship that exists between a panel and the numerical value representing the calculation performed on the panel; 2) the method will work for any calculated data set; and 3) the GDD method will interface with the existing ACTION system and a standard monochrome CRT. Guidelines 2 and 3 above would follow once the first guideline was established.

Normally, the geometric representation of the vehicle is constructed on the face of the CRT as a series of panels drawn in a preset manner. For example, the aircraft shown in Fig. 2 would be drawn from nose to tail panel by panel. The GDD technique was set up to reorder the set of graphic commands that draw the panels so that the resulting display unfolds in a manner such that the order of panel display correlates with the calculated value for that panel. This is accomplished by first rearranging the numerical values in an array from lowest to highest value. This in turn will effectively provide a means to reorder the panels. Now when the same aircraft is drawn on the CRT the panels will be drawn in an order that corresponds to their numerical value. This will allow an examination of the distribution of the calculated values wherein the display of the configuration reveals the data distribution.

The development of the GDD method will now be described in more detail, followed with an example to demonstrate its use.

Graphic Data Display Technique

Two sets of information are required as input for the GDD method, a geometric definition of the vehicle (GEMPAK geometry) and the array of calculated values corresponding to this geometry. To establish the bounds on the information to be displayed, the file containing the array of panel values is searched to locate the minimum and maximum values. These values are in turn used to group the data values in groups equally spaced between the minimum and maximum. Figure 4 will be used to illustrate how this is accomplished prior to the graphic display.

Figure 4 shows the aircraft configuration shown before, however, this time the fuselage has been simplified and the upper surface is represented by only 20 panels in four strips of five each. A set of values is listed representing a possible set of calculated values. The minimum and maximum values have been flagged. Using this information the panel data are placed in groups which represent a particular percentile grouping of the numerical values. In this example the data are broken into 25 percentile groups for simplicity with the values being placed in the groups shown. Group 1 will contain all the panels whose values fall in the upper 25% range of the data or between values of 725 and 860. Similarly, the other three groups will contain the panels whose values fall within their ranges. Note that this does not evenly distribute the panels nor was it intended to. A different percentile grouping could have been selected, 25% was used only for this example. This selection could be changed depending on the particular application.

Each panel in Fig. 4 is now associated with a group and therefore a unique group number or integer value. In this example, panels 1, 2, 6, 7, 11, 12, 16, 17, and 18 are assigned the integer value 1. Similarly, the remaining panels are associated with an integer value as indicated in Fig. 4.

With the panels ordered, the next step is to create a graphic display wherein the integer grouping can convey the distribution of the data. Several ideas came to mind or were proposed which would graphically present the data. The first attempt to graphically display the data involved assigning a different line type to each integer grouping (dotted, dot-dash, etc.). The entire aircraft was then drawn on the screen with the hope that the different line types would show how the data varied over the vehicle. Unfortunately, the complexity of the geometry made the display too confusing and impractical to use. This approach did lead to the second idea, which might alleviate the problem of identifying which groups of panels had similar numerical data values.

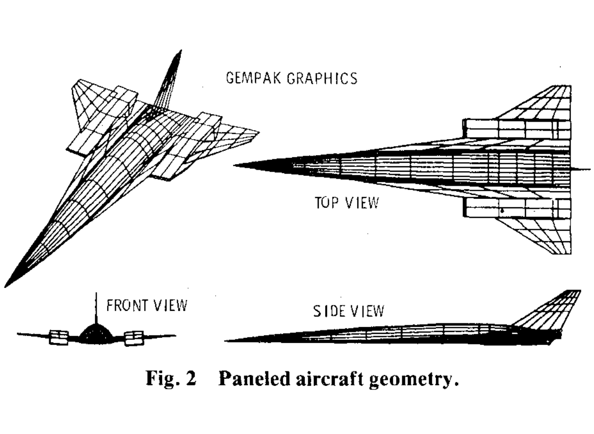


Fig. 2 Paneled aircraft geometry.

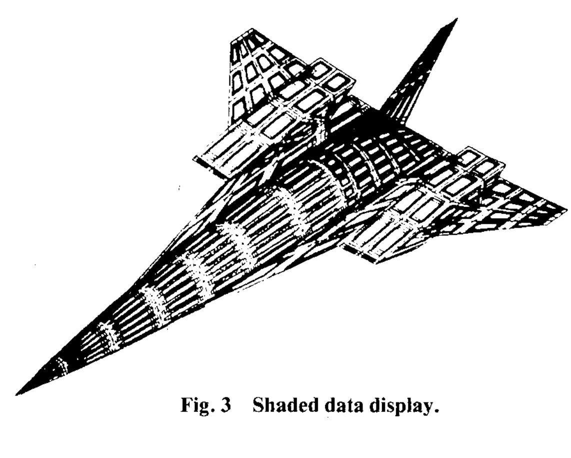
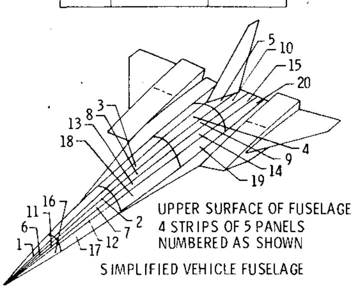


Fig. 3 Shaded data display.

GROUP	NUMERICAL VALUE RANGE	NUMBER OF PANELS
1	725-860	9
2	590-725	4
3	455-590	5
4	320-455	2



PANEL NUMBER	PANEL VALUE		GROUP NUMBER
1	760		1
2	700		1
3	600		2
4	480		3
5	320	* MINIMUM	4
6	780		1
7	730		1
8	670		2
9	510		3
10	340		4
11	800		1
12	760		1
13	700		2
14	560		3
15	500		3
16	860	* MAXIMUM	1
17	800		1
18	780		1
19	600		2
20	480		3

Fig. 4 Example of panel numbering and group assignment.

The CRT on which the display is being generated is a common storage tube device. This CRT had available a refresh buffer which could refresh a limited set of vectors. The idea was to avoid the problems encountered above by only working with one integer group at a time. The entire geometry would be displayed on the screen with the panels in a particular group drawn in the refresh mode. In this manner they could be identified with respect to the remaining geometry by blinking these panels. However, this approach was not pursued because of difficulties in using the refresh buffer. In particular, the refresh buffer was too limited in vector length and difficulties in obtaining permanent copies were foreseen. This method and the previous one did lead to the data display method now in use.

First, remember the panels have been ordered or assigned a unique integer value. With this in mind a display can be created in which a picture of the aircraft can be systematically constructed by displaying a single integer group at a time. Each group will contain those panels whose values fall within a known range of values. With the addition of each new integer grouping the picture grows until the complete view is visible. During this sequence a permanent copy of the display can be made to document the picture buildup. To illustrate the GDD technique a heating analysis was performed on our aircraft configuration which is similar to one reported on in Ref. 3.

Figure 5 is a portion of a table showing the integer groupings of the temperature data. The data are divided into 20 groups (five percentile groups) whose integer values range from -10 to 10. Included in the table are the integer value, number of panels assigned that integer, percent of the surface area those panels represent, and the minimum and maximum values representing the bounds on the integer groups. This table is presented to the user before the display begins and is a useful indication of the data distribution.

Figure 6 presents the corresponding picture buildup for the aircraft. The buildup is in ten percentile groupings of the data or for each two consecutive integers shown in Fig. 5. It is very clear from this display which panels lie within defined temperature ranges. Note that as expected the engine leading-edge surfaces and the lower surface experience the highest temperatures. The lowest temperatures occur on the top rear fuselage panels.

Normally, only panels on the aircraft with normal vector components in the direction of the viewer are drawn. This eliminates most of the hidden lines and resulting confusion especially with complicated configurations. This also means that about half the panels of interest are not visible, but by displaying two views simultaneously, one of the upper surface and one of the lower surface, the viewer can usually see all of the panels. This allows all the data to be examined in a single pass through the display buildup. Several options are available to help the user examine the available data. The most valuable of these is the zoom option.

			ENTIRE TABLE NOT SHOWN		
INTEGER VALUE	-10	-9		-2	-1
NUMBER OF PANELS	4	2		188	114
% OF TOTAL AREA	0.6	0.3		24.2	20.5
MIMIMUM VALUE	127	197		688	758
MAXIMUM VALUE	197	267		758	829
INTEGER VALUE	1	2		9	10
NUMBER OF PANELS	70	14		34	6
% OF TOTAL AREA	12.4	3.7		0.04	0.02
MINIMUM VALUE	829	899		1390	1460
MAXIMUM VALUE	899	969		1460	1530

Fig. 5 Tabulated data distribution from GDD code.

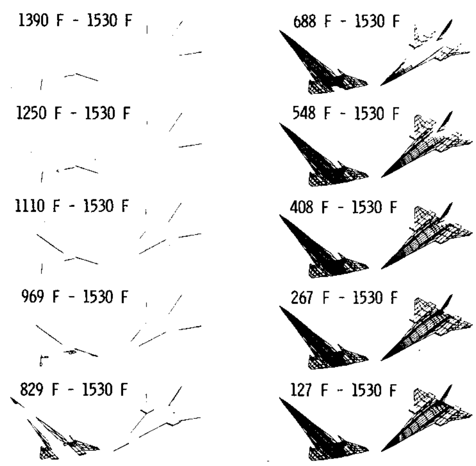


Fig. 6 GDD display of temperature distribution, $M=5$, $\alpha=6$, alt = 100,000 ft.

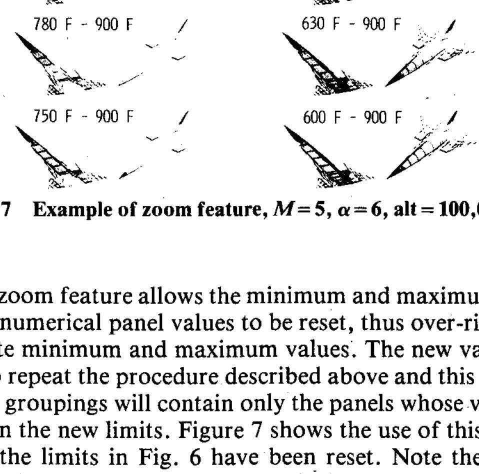


Fig. 7 Example of zoom feature, $M=5$, $\alpha=6$, alt = 100,000 ft.

The zoom feature allows the minimum and maximum limits on the numerical panel values to be reset, thus over-riding the absolute minimum and maximum values. The new values are used to repeat the procedure described above and this time the integer groupings will contain only the panels whose values lie between the new limits. Figure 7 shows the use of this feature where the limits in Fig. 6 have been reset. Note the groups contain fewer panels and that the display now provides more detail.

Color Graphics Extension to GDD

The GDD technique discussed so far allows for fairly rapid examination of the distribution and contribution to the overall aircraft aerodynamics by individual panels. This method has proved quite useful because it was designed to operate within the ACTION system and therefore was available to the individual researcher. It uses commonly available monochrome CRT graphics terminals and permanent copies in black and white can easily be obtained. However, the technique does have its drawbacks since time is required to go through the picture development and make a copy at each step (typically 10-15 min). A logical improvement would be the addition of a color display where a single picture on the CRT would not only eliminate the need for many copies but also directly show which panels are associated with each integer group.

Color displays have been used elsewhere to represent large amounts of data or to help interpret data sets.[4-6] Recently, color graphic techniques have been used at NASA Langley to display and interpret large sets of transient heating data.[7] As shown in Ref. 7, color coded surface displays are a very effective and efficient means of examining the data. The GDD technique is structured such that it is ideally suited for extension to color graphics. The panel calculations have been ordered and each panel has been assigned a unique integer value. Color can easily be added by assigning a color to each integer and then creating a color raster display. Two types of color displays will be examined, a low resolution eight-color display and a medium resolution multicolor display.

A low-to-medium resolution CRT which could be tied into the distributed processing system was examined first to determine if the reduced resolution could be offset by the addition of color. All the preliminary one-color design work was done on a standard storage tube CRT with a resolution of 1024 lines by 780 lines. The high resolution is necessary for good graphic representation of the vehicle and to avoid the distortion caused by straight lines appearing jagged, etc. It should also be noted that even this resolution is at times questioned by the user who feels that it is not good enough. The color CRT used initially for demonstration purposes had a resolution of 240 lines by 320 lines. Figure 8 shows a color coded display on this terminal representing the same information contained in Fig. 6.

This figure is an eight-color display of the data where black has been assigned to the background leaving seven available colors for data representation. It was necessary to compress the integer groups from 20 to 7 so that each group could be assigned a color. The integer groups were uniformly compressed and the color key to the right in Fig. 8 represents the variation in the data. For example, red at the top represents the lowest three integer groups. Only four colors are clearly visible in this picture because the highest temperatures occur on the leading edges and lower surface. The picture also shows some of the problems encountered with the graphics logic used by the machine, namely, failure to fill all panels with the assigned color and color overlap. No attempt was made to solve these problems since time on this terminal was borrowed. This work did show that the potential for color displays existed and that to do a good job would require more colors and higher resolutions.

A second color display was generated using the same technique and equipment described in Ref. 7. This equipment is not directly accessible via the minicomputer and access was accomplished in an off-line mode. Figure 9 shows two color coded displays, one of the upper surface and one of the lower surface. For these pictures 21 colors were used, 20 for the display and 1 for the background. This allowed each of the 20 integer groups to be represented by a single color. The resolution of this display is 480 lines by 640 lines and is compatible with the standard 525 line TV monitor. The color key below the pictures indicates the temperatures assigned to each color. Note the color assignments used in Fig. 8 were arbitrary and used the standard color scale available, whereas in the case of Fig. 9, the same color variation used in Ref. 7 is employed, namely, an aesthetic choice was made which was intended to coordinate hottest to coolest (white to blue) colors with maximum to minimum values.

The increase in detail is immediately obvious and the picture no longer appears two-dimensional or flat. The individual panels can now be discerned, which helps to show the curvature in the vehicle surface. Figure 10 shows a picture of the same vehicle except in this case the zoom option has been used and a smaller temperature range is displayed. The hot spots along the leading edges and engine surfaces are not included, thereby allowing more detail to be visible over the rest of the surface. This figure corresponds to the information shown earlier in Fig. 7.

It should be noted that the same program was used to generate both the lower resolution display and the conventional TV displays of Figs. 9 and 10. The graphics logic employed on the latter eliminated most of the display problems encountered with low resolution device and the overlap of panels or extraneous colors is not as serious.

The Performance Aerodynamics Branch is continuing its work with color and soon hopes to begin work with an even higher resolution display. This device will be able to generate 32 individual colors. The advantage of the new display generator is that it can be connected via a communication link with the Prime minicomputer thereby allowing the user (researcher) access to a color display without the need for offline manipulation. High resolution, 1024 lines by 1280 lines, will also give the researcher a color display (data distribution) system with equal or better resolution than the storage tube terminal currently being used for geometry definition. The entire computer aided design system will then access the same computer, have the same resolution throughout, and allow the individual researcher access to it.

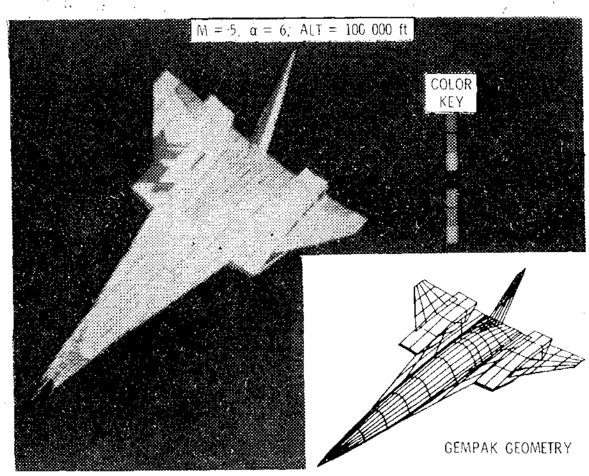


Fig. 8 Eight-color display of surface temperatures.

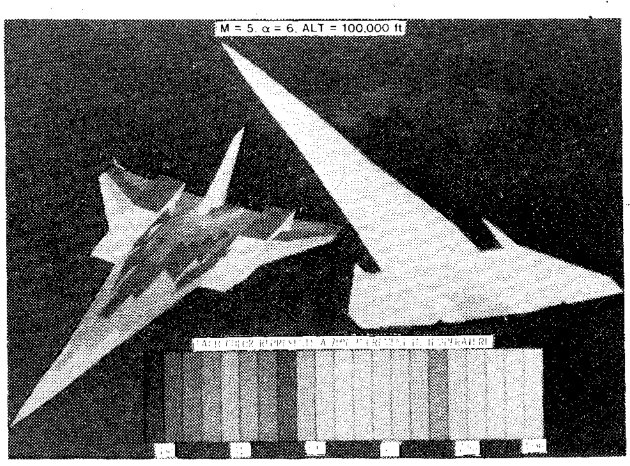


Fig. 9 Color coded display of surface temperatures.

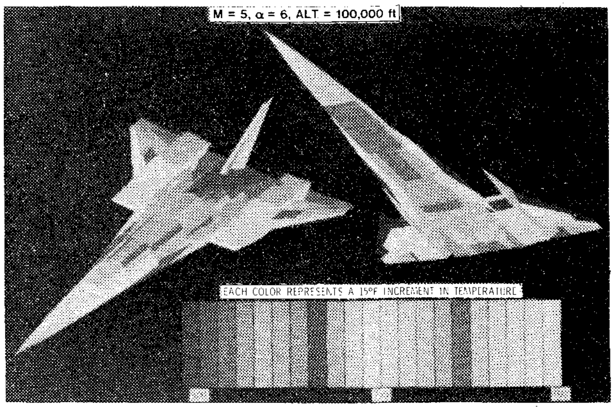


Fig. 10 Color coded display of surface temperatures—zoom option.

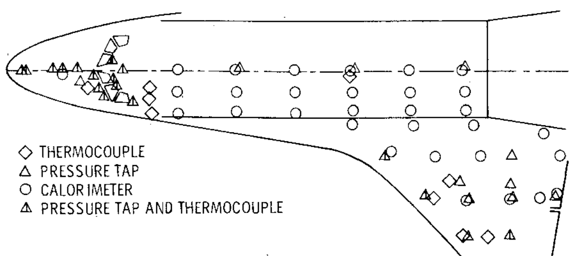


Fig. 11 Space Shuttle sensor locations.

Applications of the GDD Technique

The GDD technique as described in this paper is not limited by the type of data to be evaluated. An example has been given where the temperature distribution on a hypersonic aircraft concept was examined with the GDD technique. To accomplish this, the GDD method was interfaced with the aerodynamic analysis program of Ref. 8. Reference 9 contains more details of this implementation.

Only two input items are required to use the GDD technique, a geometry definition and a data array which corresponds to that geometry. The geometry definition is used to construct a picture on the CRT and the data are overlayed on the picture either by the use of integer groups or by the use of a color display. For the example above and for the work currently being done in this research group, a paneling scheme is commonly employed to define the vehicle geometry.

One application that has been proposed for the GDD technique is the examination of large amounts of experimental data. For example, consider the sensors (pressure, thermocouple, calorimeter) shown in Fig. 11 that have been proposed for use on the Space Shuttle. Large amounts of data will be taken during the flight tests and some rapid means of sorting through and examining the data may be advantageous. Figure 12 shows a paneled GEMPAK representation of the Shuttle. By identifying the sensor locations with a given panel or by repaneling the geometry so that each panel surrounds a sensor location, the GDD technique could be used to examine the experimental data distribution. The zoom feature could be used to identify areas where anomalies occur. Color displays could easily display the distribution and any problem areas should be readily visible.

The GDD technique has also been used to design an array of heat lamps used to preheat a wind tunnel model prior to injection into the tunnel at the desired test conditions. To accomplish this, the method was used to examine the temperatures and heating rates over the surface of the model.

A final note seems appropriate at this point. The GDD technique described above was designed to be used by a small research group where just about everyone at one time or another is sitting in front of the CRT. Therefore the technique was required to work on the standard devices available, which

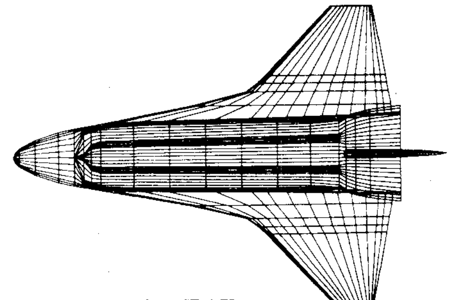


Fig. 12 Space Shuttle—GEMPAK geometry.

include a black and white hardcopy unit. The technique has been used successfully by many in the group. The color displays have improved the technique but color may not be available to everyone and there are problems even with color. First, color display systems and color copy units are very expensive. Second, there is a problem of how to include a color figure in a black and white paper or report. The use of color will be pursued but there probably will always be a use for the black and white techniques described above.

Conclusions

This paper has outlined the development of an interactive computer graphics technique known as the Graphic Data Display (GDD) which provides a means of quickly sorting and interpreting large amounts of data. The method employs a unique graphic representation of the data, which results in a picture rather than a set of numbers.

The GDD approach directly relates the geometry describing the vehicle to the data calculated on it. An example was presented showing the implementation of the GDD technique in conjunction with an aerodynamic paneling method wherein the temperature distributions on a hypersonic aircraft at its cruise condition were displayed.

Color displays were also shown to be an ideal extension for the GDD method. Comparisons were shown between a low-to-medium resolution color display and a display with TV-like resolution. The higher resolution display which employed 20 different colors greatly improved the clarity and detail available for analysis of the data.

Additional work will be required to examine the use of even more colors and higher resolution to further enhance the color display of the data. The GDD technique should also be useful for examining the large sets of data obtained during preliminary flight tests of new aircraft or spacecraft.

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