NASA Technical Memorandum 81963

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National Aeronautics
and Space Administration

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SUMMARY

An interactive computer graphics technique known as the Graphic Display Data method has been developed to provide a convenient means for rapidly interpreting large amounts of surface design data. The display technique should prove valuable in such disciplines as aerodynamic analysis, structural analysis, and experimental data analysis. To demonstrate the system's features, an example is presented of the Graphic Data Display method used as an interpretive tool for radiation equilibrium temperature distributions over the surface of an aerodynamic vehicle. Color graphic displays were also examined as a logical extension of the technique to improve its clarity and to allow the presentation of greater detail in a single display.

INTRODUCTION

The hypersonic aerodynamics group at NASA Langley Research Center since its conception has been involved with the preliminary design and optimization of flight vehicles (missiles, cruise aircraft, and spacecraft). The types of research conducted include: preliminary conceptual design and optimization studies; numerical and experimental evaluation of new vehicle concepts; and systems analysis for performance trade-offs. To facilitate the work in these areas the group set out to develop computer-aided design and analysis tools.

The first tool developed was an arbitrary aircraft-geometry generator, GEMPAK (ref. 1), which provided a rapid means to go from drawing board to a detailed set of aircraft geometry. GEMPAK proved to be very effective and was soon used extensively in conjunction with interfaces to several aerodynamic programs to aid in the preliminary design phase of aircraft and missile concepts.

Initially, a batch input mode was used and jobs were submitted to the computer and the results were returned several hours later. Researchers would often proceed on the assumption that the aircraft geometry was correct and submit an entire job, including analysis, to the computer. Many times though, errors in the geometry meant that the analysis was incorrect. Therefore, it was apparent that there was a need to quickly verify the geometry before performing the analysis.

Reference 2 documents the development by the group of a computer-aided design system specifically geared toward conceptual design by a small research group. The system operates on a distributed computing system consisting of a set of minicomputers tied via a communication link to the large mainframe computers. The goal established for the computer-aided design system was to assign the minicomputer tasks, such as graphics, for which speed and response time are most important. The number crunching would be delegated to the larger mainframe computers. In this mode the minicomputer and mainframe computer handle only those jobs for which they are best suited. This system has proved to be a very useful tool for researchers, and references 3 and 4 are good examples of the types of work that have benefitted directly from the system and its user-oriented philosophy.

Using the in-house system for the preliminary design of high-speed aircraft can lead to the generation of large amounts of aerodynamic surface data. Ideally, these data should be examined in some detail throughout the early design process to maximize the vehicle performance. However, an in-depth examination is limited by the time-consuming task of scanning and interpreting what can be a large volume of data. This in turn limits the trade-offs that can be made early in the design process or even later, depending on the amount of information to be scanned.

Therefore, in response to the needs for an efficient means of analyzing the data, an interactive computer-generated graphics display method has been developed for incorporation into the design system. This method is the subject of this report. An example is presented which shows one use of the graphics technique and how it was used to interpret the radiation-equilibrium surface temperatures over a hypersonic aircraft concept.

GRAPHIC APPROACH TO DATA INTERPRETATION

All theoretical analysis techniques for aircraft rely on the accurate description of the configuration. Figure 1, for example, shows a typical paneling scheme for an aerodynamic computer code. Design trade-offs are based on an examination of the total-vehicle aerodynamics (body, wing, tail, etc.) as opposed to a detailed examination of the individual surface-panel information. Detailed information may be available, but interpreting the large volume of data is often a difficult and time-consuming task and is usually not attempted. Therefore, a technique for rapid examination of all available information becomes a goal. Computer-generated graphic displays are commonly used to define and assist in the examination of data and appear to offer an effective solution to the problem. The remainder of this paper describes the display technique that was developed and its application to the analysis of a hypersonic aircraft concept.

GRAPHIC DISPLAY METHODOLOGY

The display technique that follows was developed in accordance with the philosophy that was behind the development of the in-house design system. This philosophy basically consists of two ideas. The first is that the resulting set of routines represents a physical package that could be used by another research group doing similar or related work. The routines could be implemented on their computer system. The second and most important idea is that it is indeed a philosophy, or a way to organize the analysis codes, graphic tools, and utilities to allow the user or researcher a means of selecting his own path through the interactive analysis system. Therefore, the display methodology employed in this technique is an attempt to ensure that the resulting display be presented in a usable form, that the user can effectively control his own path through the analysis, that the display can be changed or modified if the user feels that it needs improvement, and that the features of the method be useful to other potential applications.

Rather than start from the beginning, existing display techniques were examined to see if they could be adapted to examine the large amounts of data in a concise manner. Figure 2 illustrates two such methods. Shown at the bottom of the figure are the velocity and Mach number profiles in the nozzle portion of the two-dimensional inlet shown at the top of the figure. They were presented in reference 5 and obtained with the computer code of reference 6. The arrows shown represent both the magnitude and direction of the flow. The Mach number distribution is presented as a set of contour lines. These graphic techniques are widely used to examine and present data but require a very dense distribution of the data and/or quite sophisticated logic to generate three-dimensional displays. Therefore, for the aerodynamic paneling methods which do not employ dense paneling schemes, several techniques were investigated that could present the surface calculations in a timely straightforward manner. These included writing the numerical value on the panel or drawing the panel in a unique way (using dashed lines or shading the panel). For simple geometric shapes represented by a few panels, these two techniques could be used to effectively convey information. For more complicated geometries, some method is needed whereby data can be presented with respect to the surface geometry in an unambiguous manner. Toward this end, a unique graphic display method has been developed which makes use of a high-resolution cathode ray tube (CRT) to interpret the information generated on each panel.

The Graphic Data Display (GDD) technique utilizes the one-to-one relationship that exists between a panel and the numerical value representing the calculation performed on the panel. Normally, the geometric representation of the vehicle is displayed on a high-resolution CRT as a series of panels drawn in a preset manner. For example, the aircraft in figure 1 could be conventionally drawn from nose to tail panel by panel. The GDD technique reorders 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 panel values in an array from lowest to highest value. This in turn effectively provides a means to reorder the panels. Now the same aircraft in figure 1 can be drawn on the CRT, but this time the panels are drawn on the screen in an order corresponding to their numerical value. The display itself reveals the data distribution over the geometry through the timewise order of display.

GDD TECHNIQUE

Two sets of information are required as input to the GDD method, a geometric definition of the vehicle and the array of calculated values associated with the paneled geometry. To establish the bounds for the information to be displayed, the file containing the array of panel values is searched to locate minimum and maximum values. Figure 3 is used to illustrate how the information is reordered prior to the graphic display.

Figure 3(a) shows a paneled missile fuselage. A skewed view of this geometry is shown in figure 3(b) along with a set of temperatures which represent a possible set of calculated values for this geometry (fuselage only). The maximum and minimum values have been flagged. Using this information, the panel data are placed in groups which represent a particular percentile grouping of the numerical values. For example, breaking the panel data into four groups for simplicity results in the order shown in figure 3(c). Group 1 contains all panels whose values fall in the upper 25-percent range between the minimum and maximum values. Similarly, the other groups contain the panels that fall within their ranges. Note that this does not evenly distribute the panels among the groups nor was it intended to. Also, the selection of 25-percent groupings is only used as an example and can be varied depending on the application. Each panel in a group is assigned a unique integer value. For example, panels 21, 17, 13, 9, 5, and 1 are assigned the integer value 1. Similarly, panels 22 and 18 are assigned the integer value 2; panels 14, 23, 10, 19, 15, 20, 6, 16, and 2 the integer value 3; and panels 11, 12, 7, 8, 3, 4, and 24 the integer value 4. Now each panel has a unique integer value that corresponds to the group to which it is assigned.

With the panels ordered, the graphic display program systematically constructs a picture of the aircraft by displaying one integer group at a time. Each group represents a set of numerical values which fall within a prescribed range of values. With the addition of each new integer grouping, the picture builds up on the CRT screen. At each point in this sequence, a permanent copy of the display can be made to document the picture buildup. To illustrate this point, a heating analysis was performed on the missile concept shown in figure 4. The analysis was for a Mach 6 flight condition with an angle of attack of 7°. This concept is similar to one discussed in reference 7. The buildup sequence for the missile is presented in figure 5. The sequence consists of six displays beginning with display 1 in the upper left-hand corner and progressing to display 6 in the lower right-hand corner. This sequence shows a complete view of the missile. Normally, only panels with normal vector components pointing towards the viewer are drawn. This is quite useful since it eliminates most of the hidden lines and resulting confusion; however, about one-half the panels are no longer visible. By displaying two views simultaneously, one of the upper surface and one of the lower surface, the viewer can usually see all the panels in each display, and their values can be examined in a single pass through the display buildup.

Display 1 shows all the panels assigned to group 1 - surface temperature between 1255 K and 1377 K. As expected, the engine-inlet leading-edge surfaces experience the highest temperatures. No panels on the upper surface have temperatures in this range.

The sequence continues and those panels assigned to group 2 are added to the display, creating display 2. This display now identifies the panels whose surface temperatures lie between 1127 K and 1377 K. Those panels whose values are between 1127 K and 1255 K have been added to display 1. Again, since the analysis was done at an angle of attack, the lower surface in the region of the missile nose experiences high surface temperatures. A few of these panels are also visible in the upper-surface view on the right of display 2.

The display buildup continues and display 3 adds those panels with values between 1005 K and 1127 K, so that the resulting display shows all panels with surface temperatures between 1005 K and 1377 K. Note that some panels on the upper surface are now becoming visible. Similarly we progress to display 4 and pick up most of the panels on the lower surface and the missile fin. The final two displays reveal the surface-temperature distribution over the upper surface and the wings. At each point in the buildup sequence, a permanent copy of the display can be made to document the buildup. Afterwards, a sequence like that shown in figure 5 is available, and the researcher can use it to pinpoint problem areas or map the surface values.

Several features have been added to the GDD method to improve its usefulness and allow the user to control the display buildup. Table I(a) is a data breakdown that is presented to the user prior to any display. As shown, the data are divided into 20 groups (5 percentiles each) whose integer values range from -10 to 10. Included in the table are the integer value, the number of panels assigned that integer, the percent of the surface area that those panels represent, and the minimum and maximum values of the bounds of the integer groups. For example, integer group 2 contains 14 panels whose areas comprise 3.7 percent of the total vehicle surface area and have surface values ranging from a minimum of 899 to a maximum of 969. This tabulated data display provides the user with an initial look at the data before the display buildup begins. The display shown in figure 5 represents an automatic display of the tabulated data, but the user has the option to control and select the range of values displayed.

The control of the display is accomplished through the use of a finer detail option. This option allows the user to override the minimum and maximum values of the data and reset them to values of interest. Table I(b) illustrates this feature. The limits of table I(a) have been reset to a minimum of 600 and a maximum of 900. Now only those panels whose surface values lie between these limits are grouped. The remaining panels are ignored. Note that the groups now contain fewer panels and the display buildup provides more detail on the data distribution over the surface. Figure 6 shows an example of the finer detail option. In this case, the limits have been reset to a minimum of 755 K and a maximum of 1089 K. This could represent the limits of a material under consideration for the missile. Note the increased detail that is available, especially over the lower surface and around the nose. The finer detail option can be used again to zoom in even further on the data or to look only at data of interest. For example, it can be used to find surface values that exceed a design limit.

Other features available include the restart, new data options, and user control of the view displayed. The restart option allows another set of values calculated during the analysis (e.g., pressures) to be examined in a similar manner. All that is required is that a separate array contain these values. The new-data option allows the reading in of a different set of geometry and the corresponding arrays of calculated values. This also allows several flight conditions to be examined without leaving the program. If necessary, the user can also control the view displayed on the CRT. However, the two views displayed in figures 5 and 6 have proven to be satisfactory in the majority of cases.

The GDD technique described in this paper is not limited by the type of data to be evaluated. As mentioned previously, only two items are required in order to use the GDD method, a geometry definition and a data array which corresponds to that geometry. An outline of how the GDD technique is interfaced with an aerodynamic analysis program is presented in figure 7(a). Typical parameters that might be calculated by such a program and might be usefully subjected to graphical analysis include local panel C_p (coefficient of pressure), lift-drag ratio, local temperature, local heating rate, etc. The technique would also be useful in displaying the large amounts of information derived from experimental tests as illustrated in figure 7(b). The next section includes a brief discussion of how the GDD method has been implemented as a tool in the interactive design system.

IMPLEMENTATION OF GDD FOR ANALYSIS OF AIRCRAFT DATA

The GDD technique has been demonstrated by implementing it as a tool in a preliminary aircraft design and analysis system. As outlined in figure 7(a), two steps precede the use of the GDD technique. In the first step the aircraft geometry is interactively input with the GEMPAK geometry package (ref. 1) and verified by visual inspection and examination of the numerical model (point definition). The second step in the process is the actual analysis of the input geometry at a given flight condition. For the example that follows, the analysis was performed by the technique described in reference 8.

This technique required only a few minor modifications to make the individual panel calculations available. Normally, the program calculates the coefficients on each panel, one at a time. After the properties on each panel are calculated, they are incrementally summed into the total aerodynamic characteristics. At this point in the calculation, modifications were made to the program of reference 8 to save the individual-panel calculated values for use by the GDD method. Provisions were made to save up to seven different types of calculated panel values including pressure coefficients, force coefficients, and heating parameters. The calculated values associated with each panel and the geometric description of the panels act as input to the GDD program. The analysis then proceeds as outlined previously and in the example that follows.

The aircraft concept to be examined is similar to one reported in reference 9 and shown in figure 1. Note that the inlet leading edges were defined as theoretically sharp and thus are not calculated. Figure 8 shows a complete sequence mapping of the radiation-equilibrium heating at a flight Mach number of 5, an altitude of 30.48 km, and an angle of attack of 6°. The buildup is in 10-percentile groupings and, as expected, the highest temperatures occur along the leading edges of the wings, vertical tail, and engine inlet. The first four displays appear to be very similar, but the GEMPAK geometry package allows for increased detail along the leading edges (leading-edge radius); therefore, many panels are packed in these areas. The leading edges have temperatures in the range of 794 K to 1105 K. Because of the angle-of-attack flight condition, the lower surface of the vehicle experiences higher temperatures than the upper surface. This is illustrated in displays 5 and 6. The final four displays reveal the surface-temperature distribution over the upper surface. Note that the lowest temperatures occur on the top rear fuselage panels. The finer detailed feature could be used to further break down the distribution on the upper or lower surface, or even to locate areas that may require special surface materials.

The GDD technique for examining the temperatures on the aircraft configuration required only a few minutes at the computer terminal, as opposed to a much longer period of time required to locate temperatures according to their x, y, z location. Since the data are already sorted, it is possible using the GDD technique to examine only the areas where the temperatures are above a design limit. The other temperatures may not be important in the initial analysis since they fall within acceptable limits. The GDD technique has been used to examine the temperature distributions on other aircraft concepts as well and has proven to be an effective method of obtaining the temperature information during the early design process. A brief example of this is presented in figure 9. Figure 9(a) shows the curved-surface test apparatus (CSTA) model, which was designed to be a test bed for the development of metallic thermal protection systems for advanced space transportation systems. The surface temperatures were displayed using the GDD technique as shown in figure 9(b). This information and the GDD display of the heating rates over the surface were used to design an array of heat lamps to properly preheat the CSTA model before injection into the Langey 8-Foot High Temperature Structures Tunnel at the desired test conditions. The pressure distribution over the model surface obtained with the GDD technique was in turn used to size the metallic thermal-protection-system concept to be tested on the CSTA model. The use of the GDD technique eliminated many hours of work for the researcher who no longer had to examine large stacks of computer output to obtain the necessary surface details.

COLOR GRAPHICS EXTENSION TO GDD

The GDD technique discussed in this paper allows a fairly rapid look at the distribution and contribution to the overall aircraft aerodynamics by individual panels. The method has been very useful because it was designed to function on a standard high-resolution one-color storage-tube display terminal. However, the technique does have its drawbacks. Time is required to go through the picture development and make permanent copies of the sequence. Color displays could simplify this process and eliminate the need for making many copies; it should be directly evident which panels are associated with each integer grouping.

Color graphic techniques have been used to represent large amounts of data or to help interpret data sets (refs. 10 and 11). Recently, color graphics have been used at NASA Langley Research Center to display and interpret large sets of transient heating data (ref. 12). As shown in reference 12, color-coded surface displays are a very efficient means of examining the data. The GDD technique is structured so that it is ideally suited for extension to color graphics. The panel calculations have been ordered and each panel has a unique integer value associated with it. Color can be added by assigning a color to each integer and then creating a color raster display as described in reference 12. Figure 10 shows two color-coded displays representing some of the information contained in figure 8. More detail is available by using more colors. Figure 10(a) shows the color-coded distribution on the top surface, and figure 10(b) is the distribution over the lower surface. Reference 13 contains a more detailed discussion on the addition of color to the GDD method.

CONCLUDING REMARKS

An interactive computer graphics technique known as the Graphic Data Display (GDD) has been developed which provides a means of quickly sorting and interpreting large amounts of surface design data. The method employs a unique graphic representation of the data which results in a picture rather than a set of numbers. The display technique should also be useful in several areas involving large amounts of information, such as structural analysis and experimental tests, where the geometry can be represented as a set of panels.

The GDD technique has been implemented in conjunction with aerodynamic surfaces for aircraft surface analysis. The GDD approach allows a visual display of virtually any surface parameter calculated on the panels. Examples are presented showing how the technique was used to display the surface-temperature distributions on aircraft concepts and wind-tunnel models.

Color displays are an ideal extension for the GDD method. The use of color-coded graphic displays greatly improves the clarity and detail available for analysis of the data. A color display is presented as an example and indeed offers much improvement over the one-color displays.

More work is required to improve interactive color display capability, and the recent advances in color graphics terminals should allow high resolution, multicolor displays for detailed data analysis, and improved visual optimization.

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TABLE I.- DATA DISTRIBUTION

(a) Initial data distribution

Integer value	−10	−9	−8	−7	−6	−5	−4	−3	−2	−1
Number of panels	4	2	4	8	6	26	46	52	128	114
Percent of total area	0.6	0.3	0.6	1.2	0.9	6.6	14.0	14.2	24.2	20.5
Minimum value	127	197	267	338	408	478	548	618	688	758
Maximum value	197	267	338	408	478	548	618	688	758	829

Integer value	1	2	3	4	5	6	7	8	9	10
Number of panels	70	14	6	4	10	32	0	20	34	6
Percent of total area	12.4	3.7	0.8	0.0	0.0	0.1	0.0	0.0	0.0	0.0
Minimum value	829	899	969	1040	1110	1180	1250	1320	1390	1460
Maximum value	899	969	1040	1110	1180	1250	1320	1390	1460	1530

(b) Data distribution with finer detail option

Integer value	−10	−9	−8	−7	−6	−5	−4	−3	−2	−1
Number of panels	12	10	12	12	8	16	24	32	28	30
Percent of total area	3.6	3.0	4.3	2.7	2.2	3.3	3.1	5.1	7.3	5.4
Minimum value	600	615	630	645	660	675	690	705	720	735
Maximum value	615	630	645	660	675	690	705	720	735	750

Integer value	1	2	3	4	5	6	7	8	9	10
Number of panels	18	36	24	30	16	4	18	28	14	10
Percent of total area	3.9	6.4	4.0	6.6	2.2	0.4	3.8	3.3	2.7	3.3
Minimum value	750	765	780	795	810	825	840	855	870	885
Maximum value	765	780	795	810	825	840	855	870	885	900

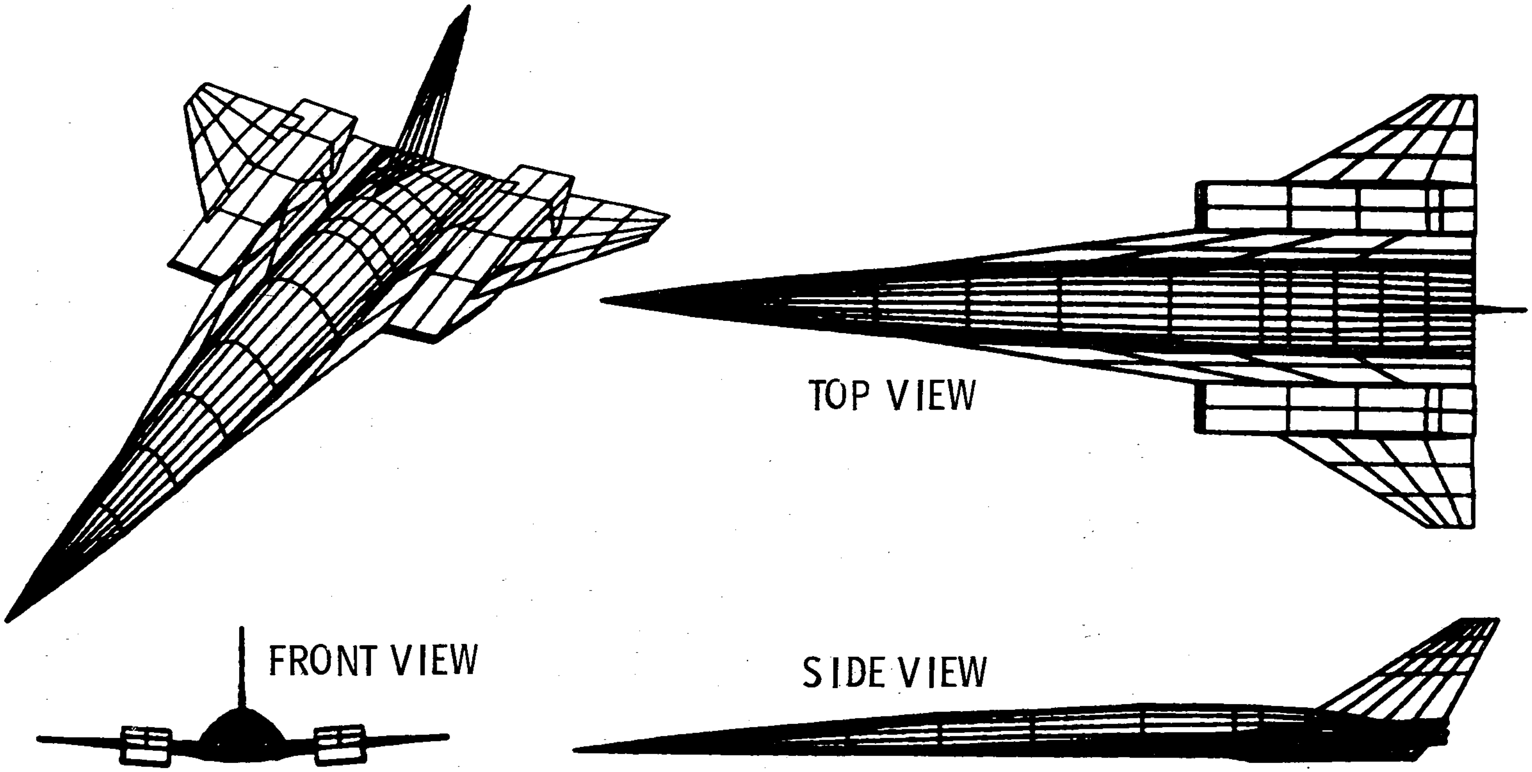


Figure 1.- Paneled aircraft geometry (GEMPAK graphics).

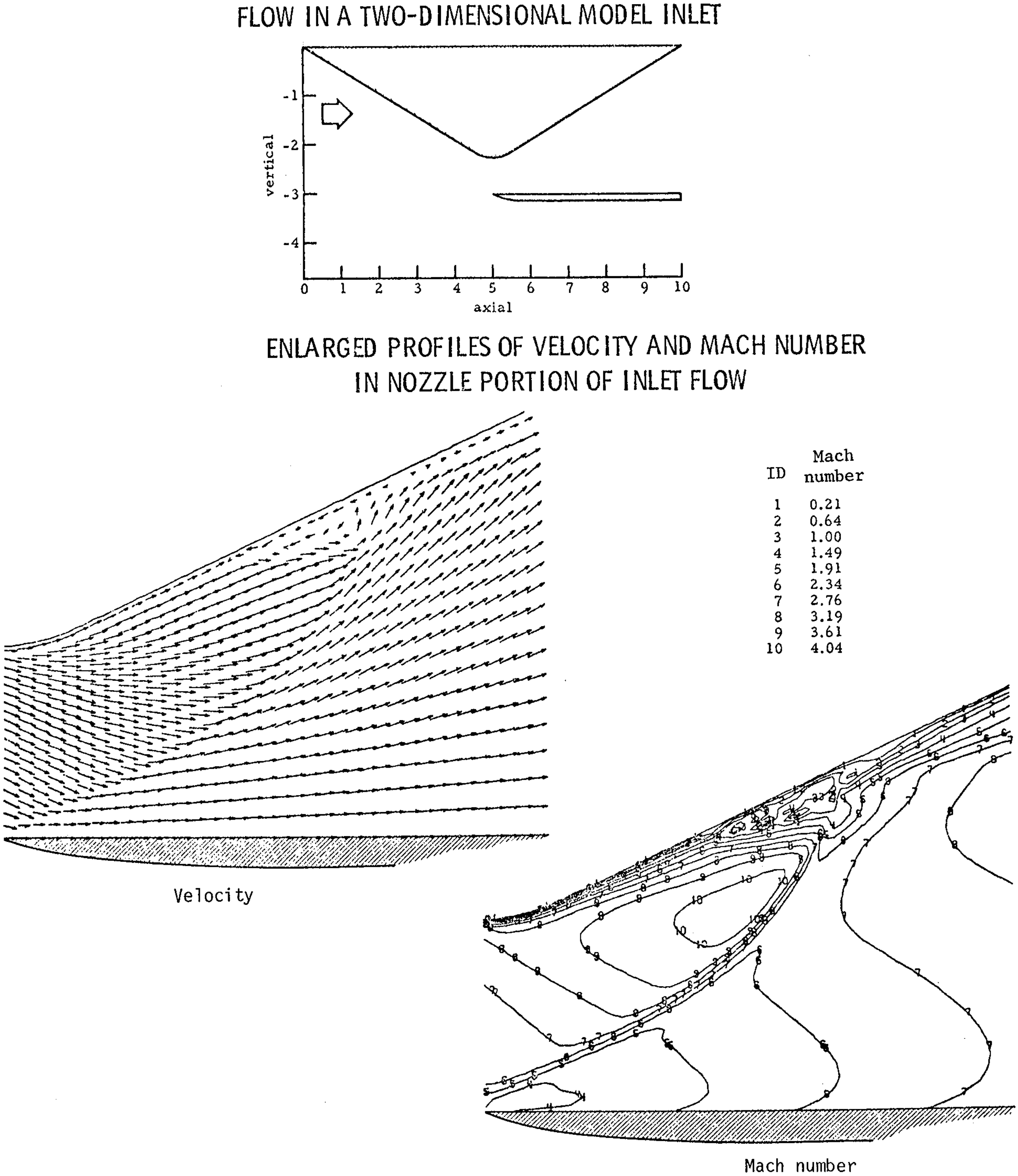
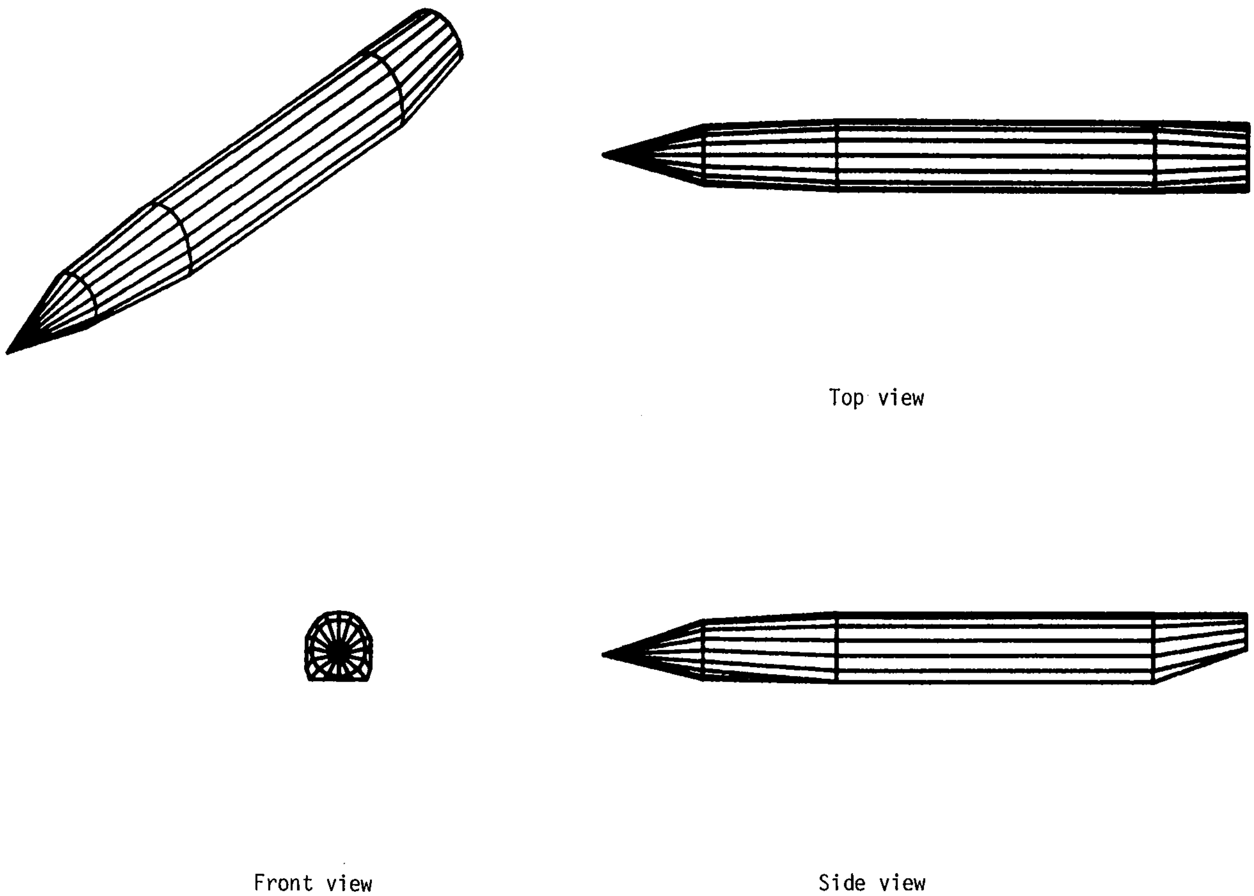
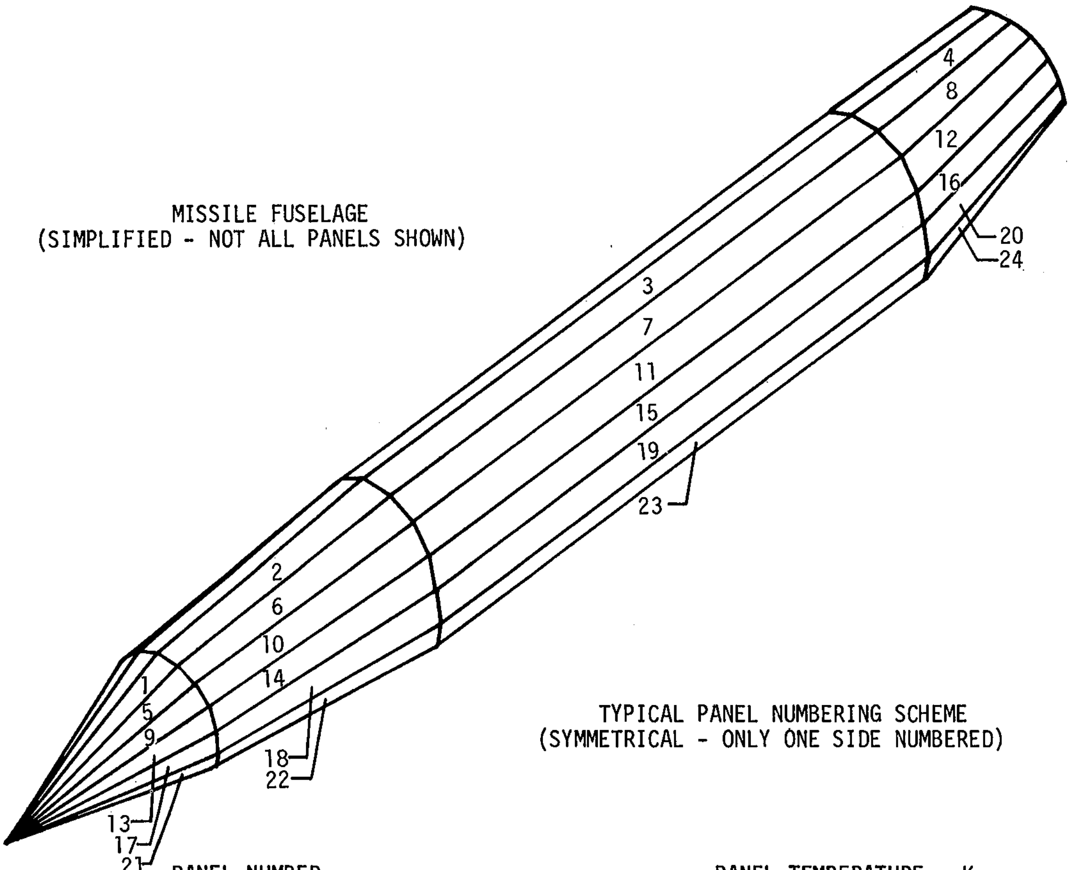


Figure 2.- Velocity and Mach number profiles in a two-dimensional inlet. All quantities are nondimensional.



(a) Paneled geometry (GEMPAK graphics).

Figure 3.- Simplified missile fuselage.



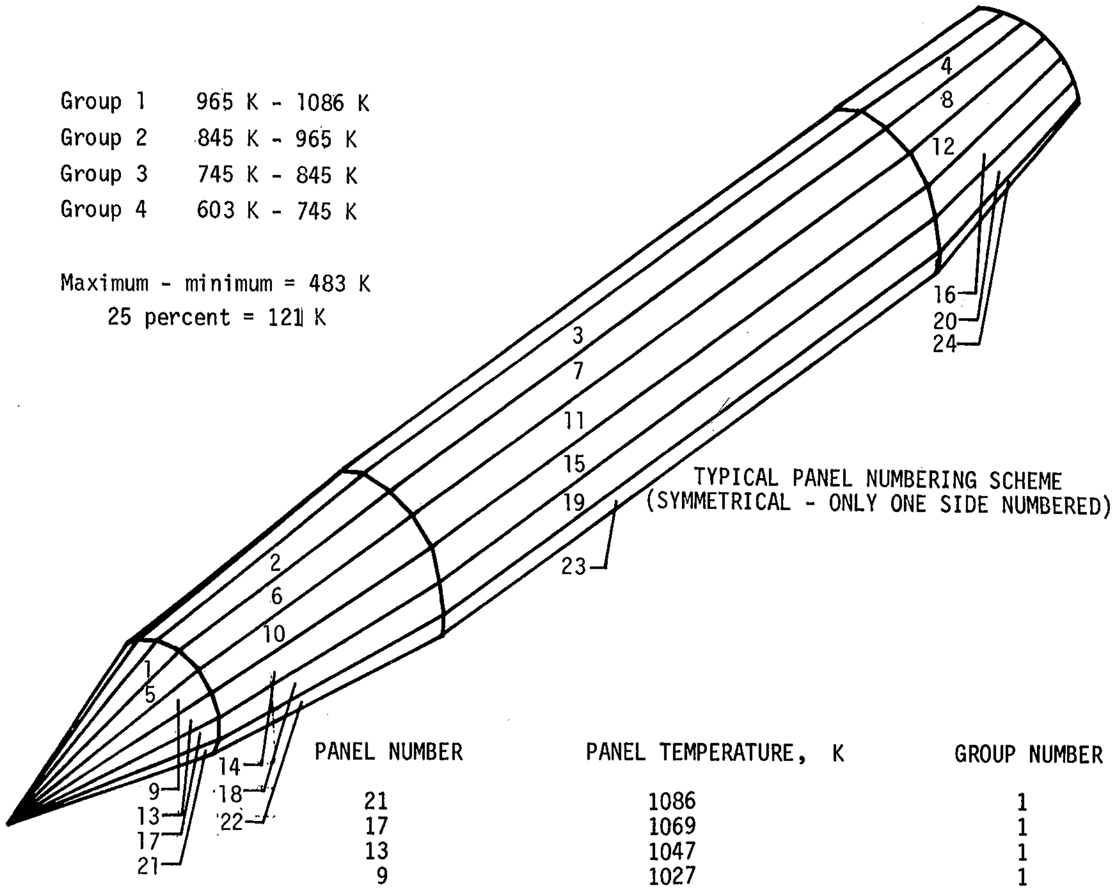
PANEL NUMBER	PANEL TEMPERATURE, K
1	1003
2	733
3	653
4	653
5	1011
6	752
7	677
8	671
9	1027
10	788
11	723
12	705
13	1047
14	838
15	772
16	745
17	1069
18	861
19	780
20	762
21	1086 *Maximum Value
22	932
23	821
24	603 *Minimum Value

(b) Panel numbering and calculatd values.

Figure 3.- Continued.

Group 1 965 K - 1086 K
Group 2 845 K - 965 K
Group 3 745 K - 845 K
Group 4 603 K - 745 K

Maximum - minimum = 483 K
25 percent = 121 K



PANEL NUMBER	PANEL TEMPERATURE, K	GROUP NUMBER
21	1086	1
17	1069	1
13	1047	1
9	1027	1
5	1011	1
1	1003	1
22	932	2
18	861	2
14	838	3
23	821	3
10	788	3
19	780	3
15	772	3
20	762	3
6	752	3
16	745	3
2	733	3
11	723	4
12	705	4
7	677	4
8	671	4
3	653	4
4	653	4
24	603	4

(c) Example of panel reordering and group assignment.

Figure 3.- Concluded.

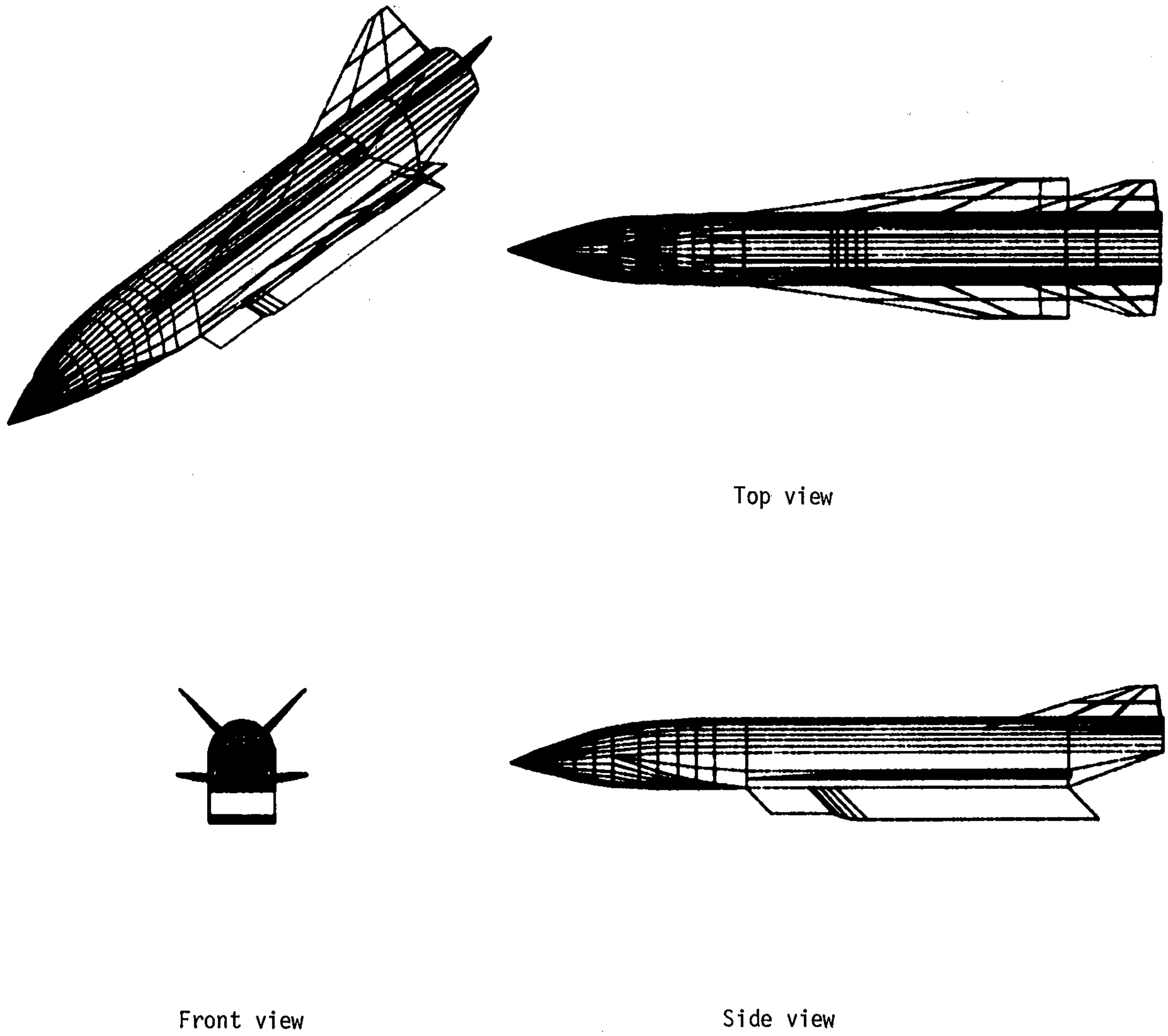


Figure 4.- Hypersonic missile concept (GEMPAK graphics).

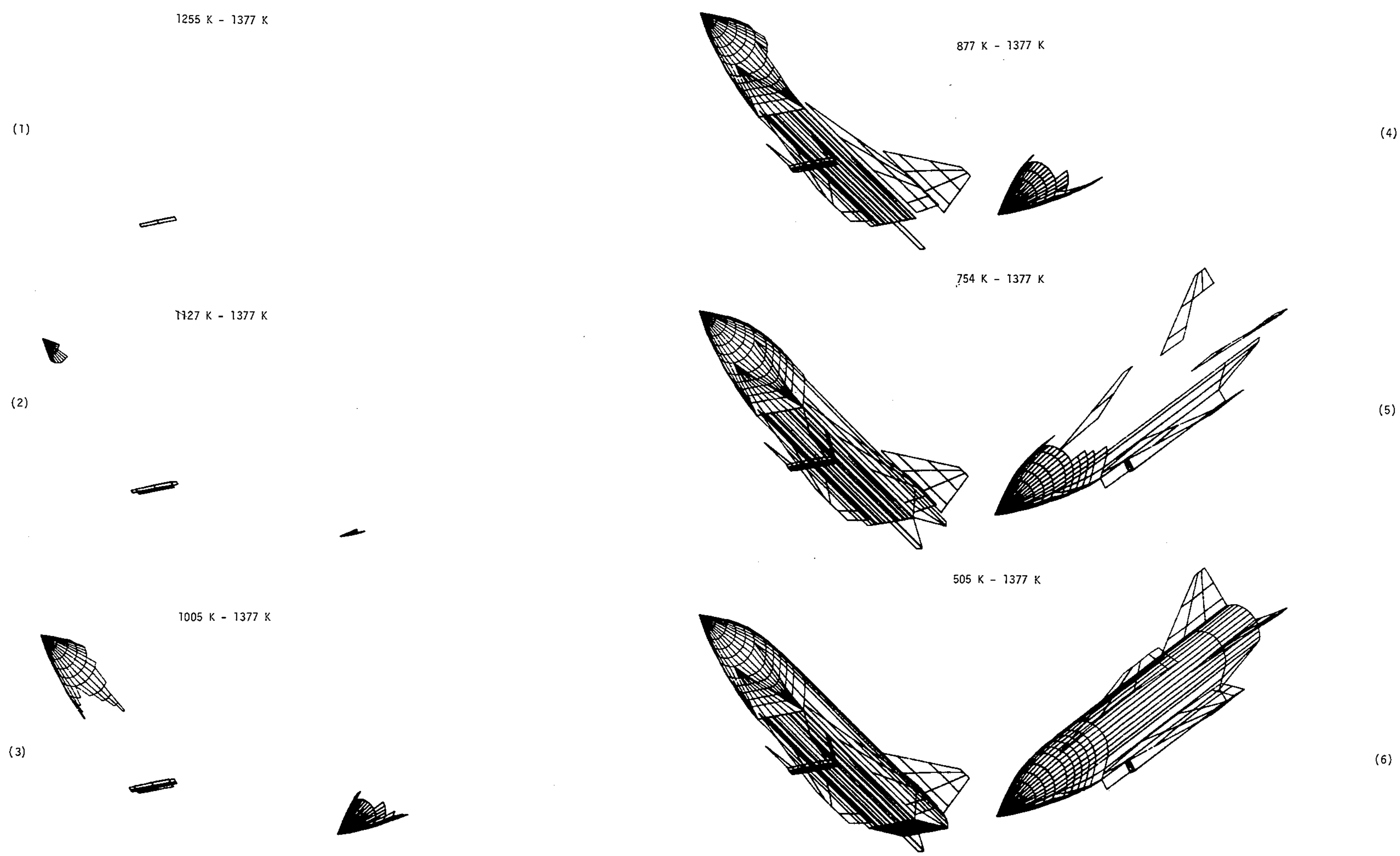


Figure 5.- GDD display of temperature distribution.

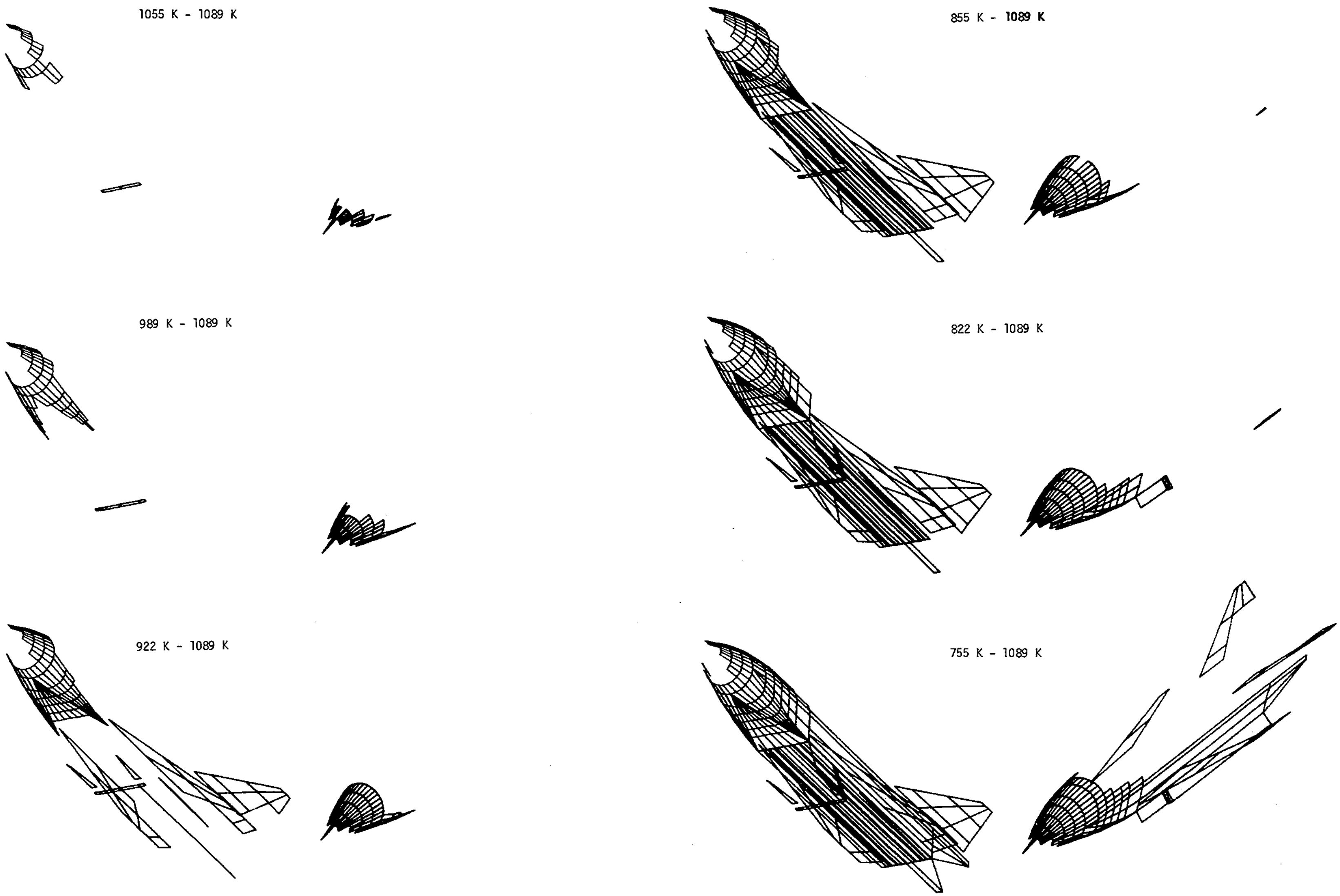
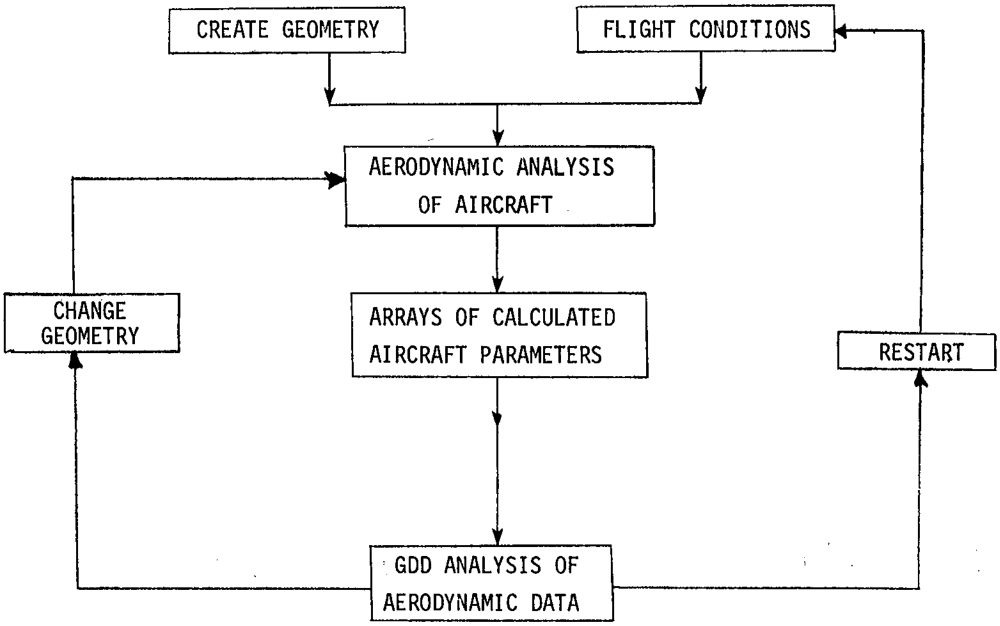
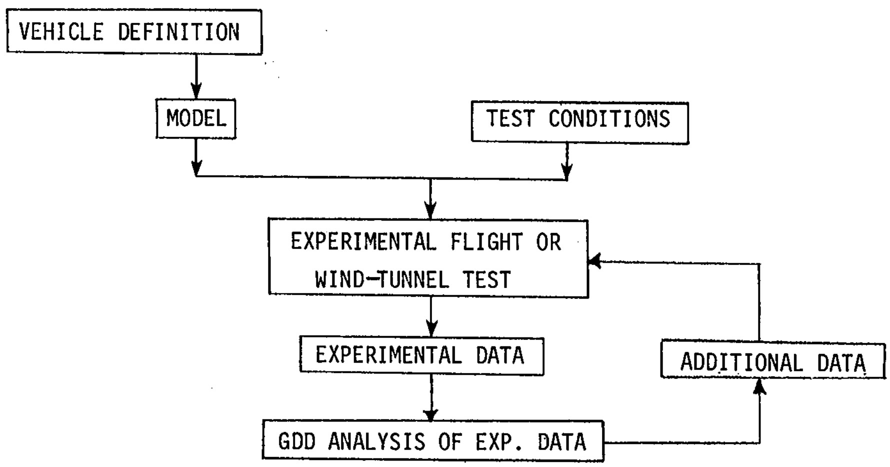


Figure 6.- Example of zoom feature.



(a) Aircraft design system.



(b) Flight or experimental data analysis.

Figure 7.- GDD flow diagram.

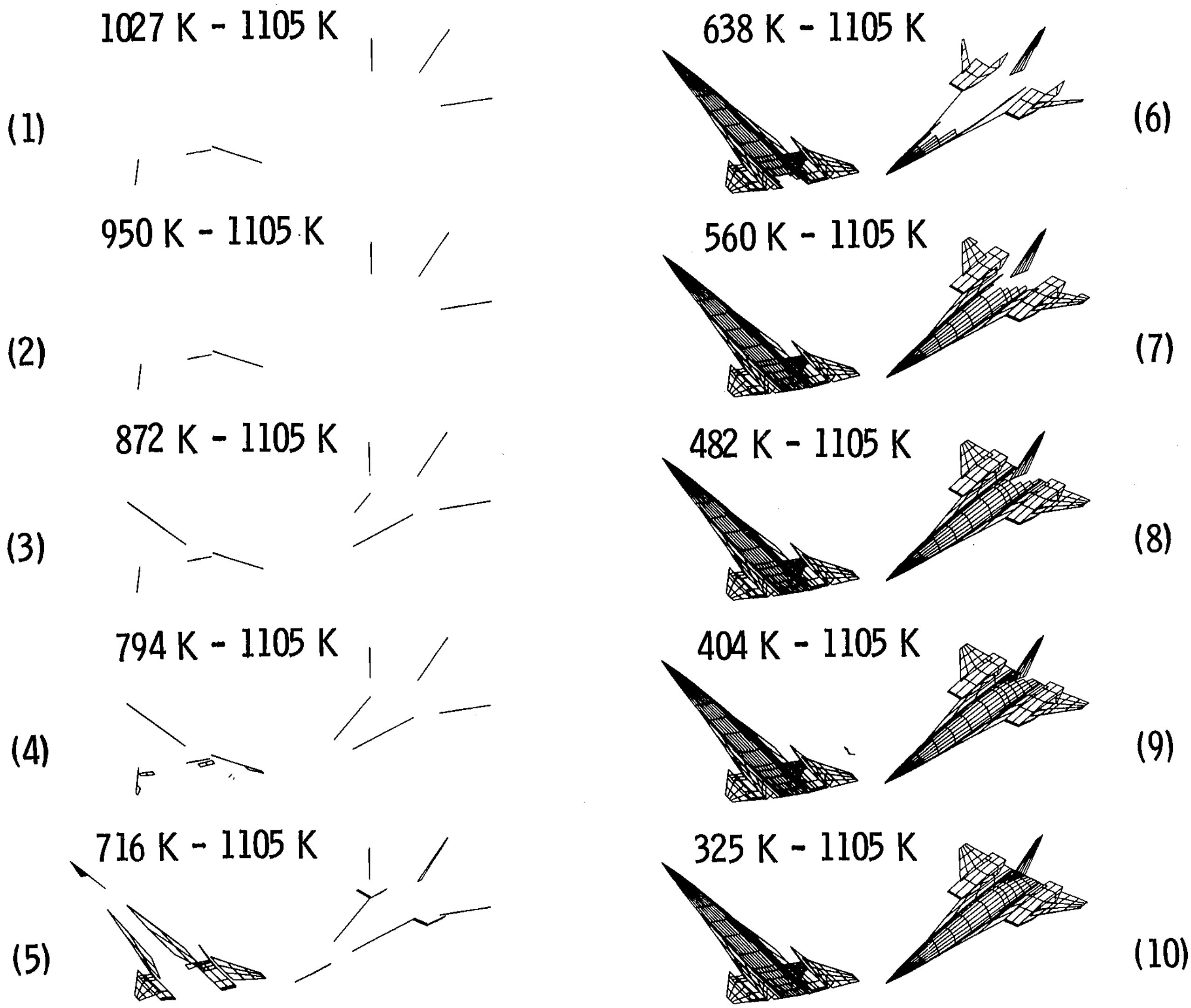
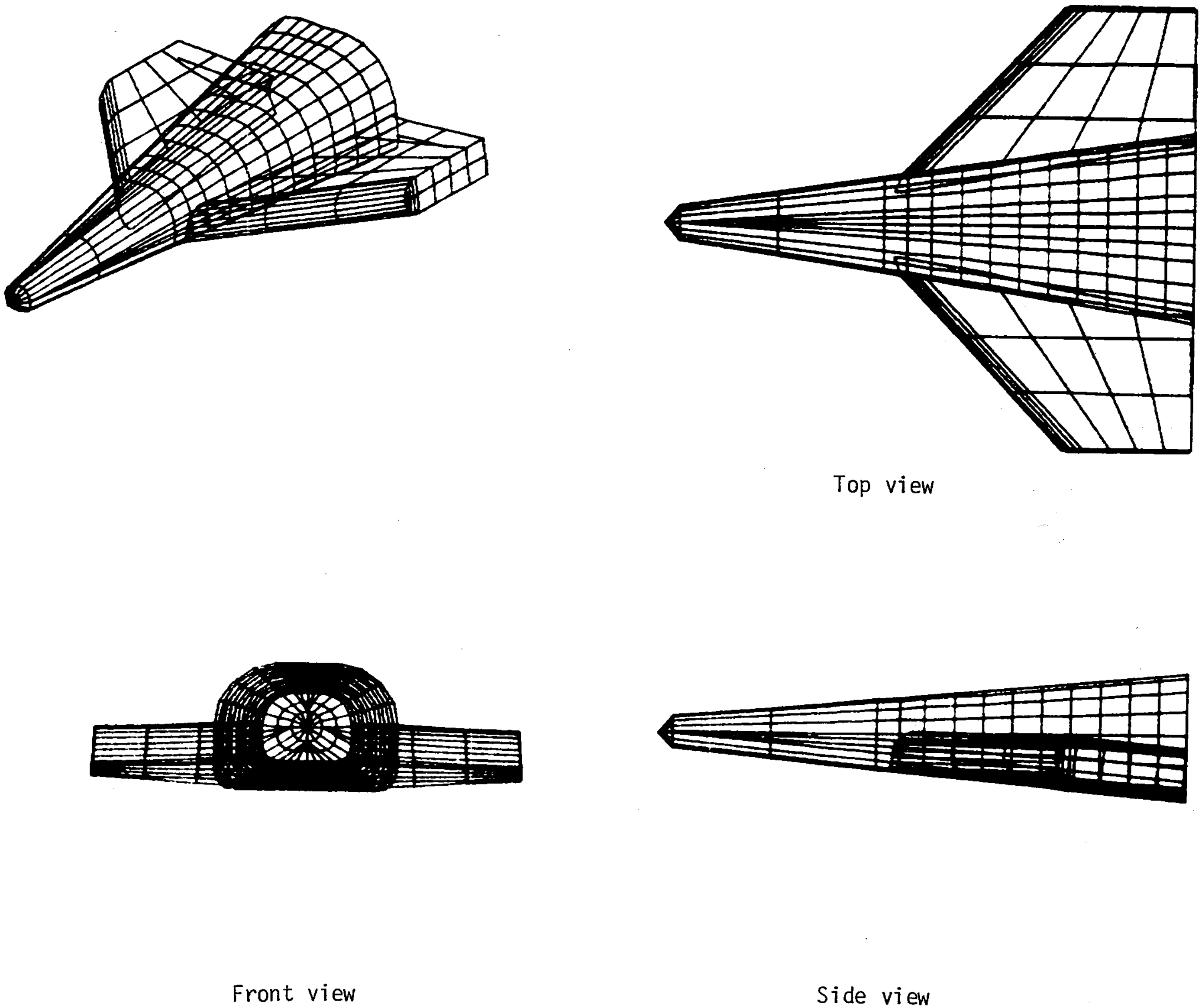
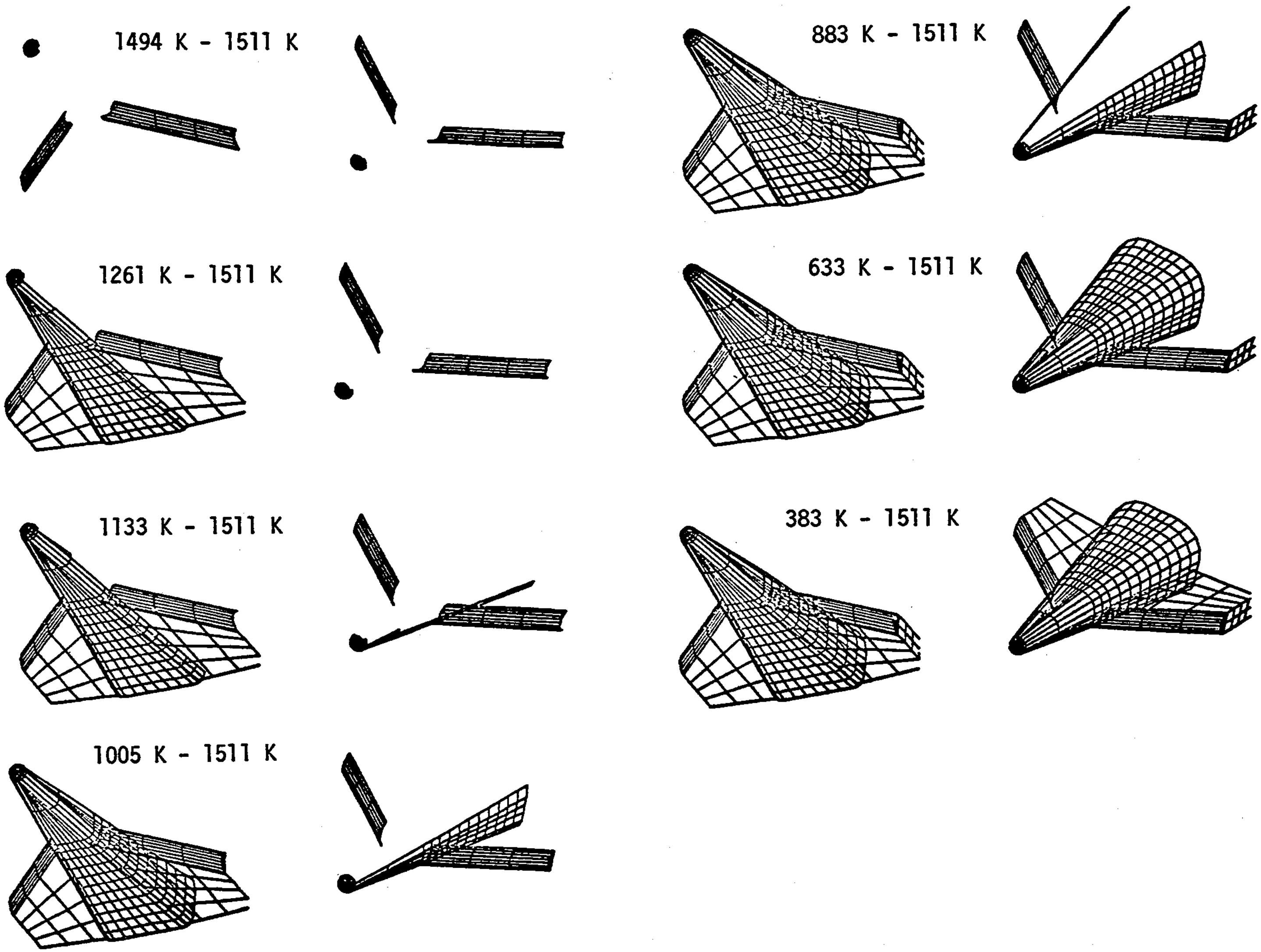


Figure 8.- GDD display of surface-temperature distribution.



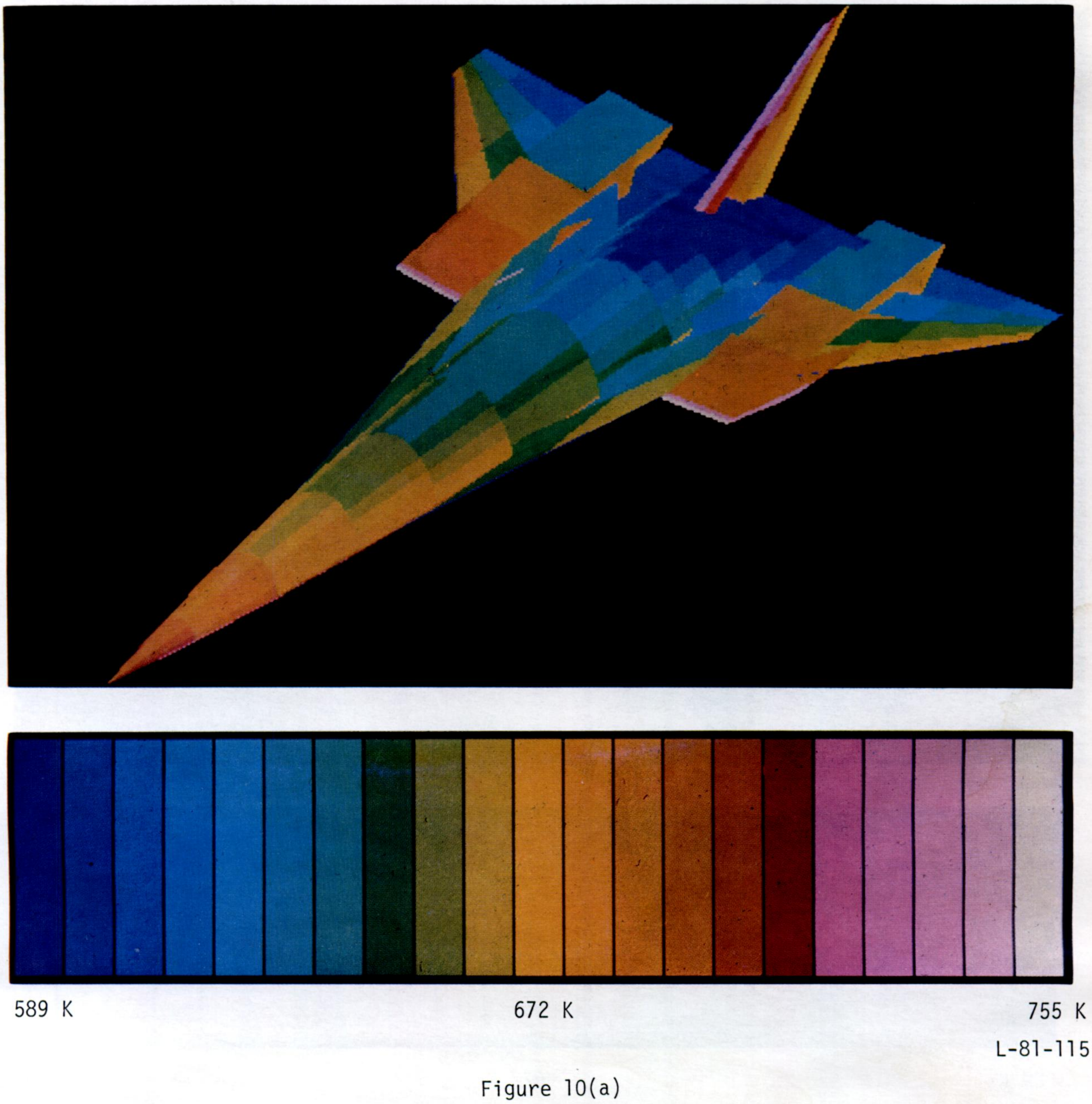
(a) Panel geometry (GEMPAK graphics).

Figure 9.- Model of curved-surface test apparatus (CSTA).



(b) Surface-temperature distribution. Mach number = 6.8; Angle of attack = 15°; Stagnation pressure = 7.24 MPa; Total temperature = 1833 K.

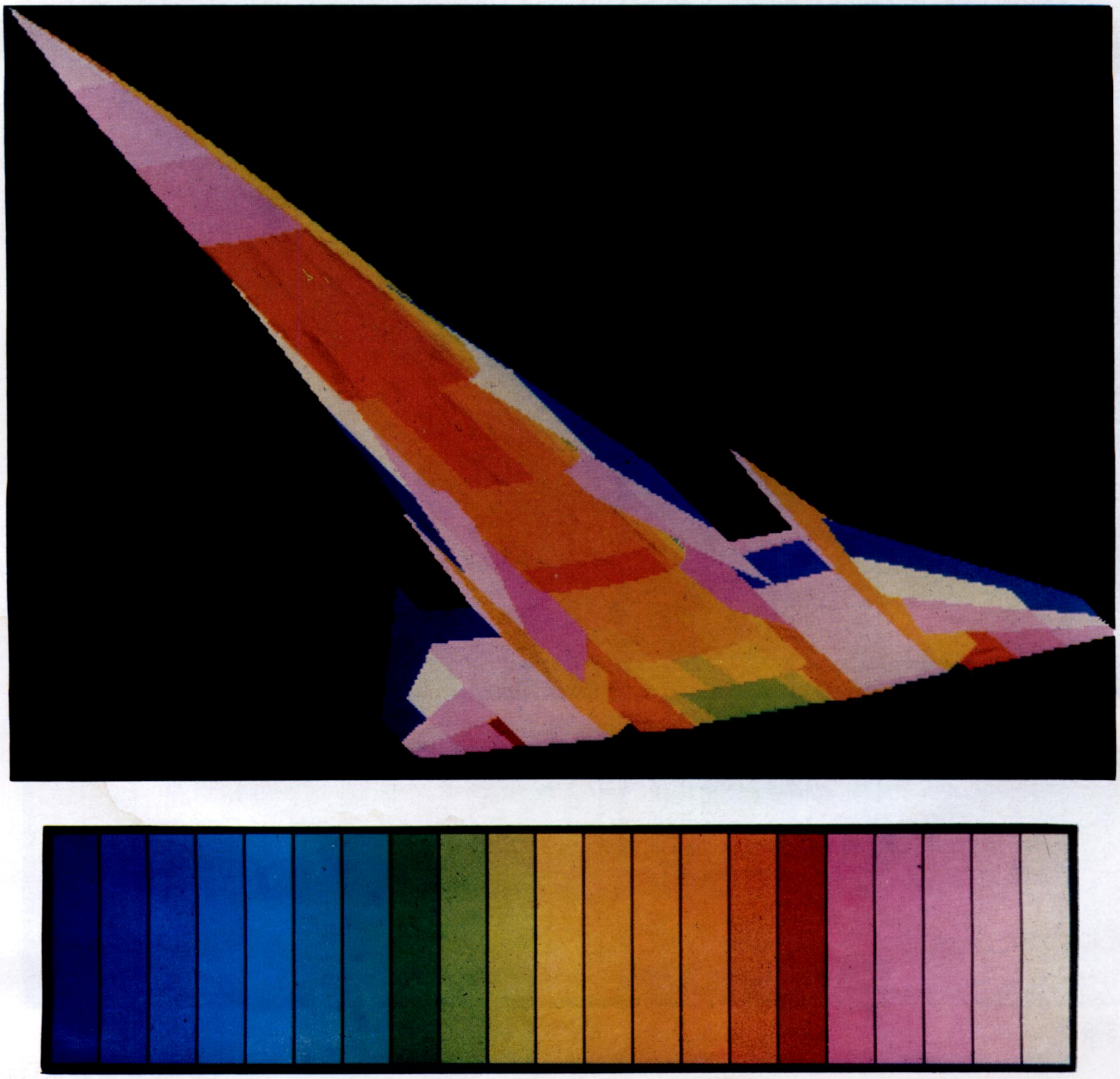
Figure 9.- Concluded.



L-81-115

(a) Upper surface.

Figure 10.- Color-coded display of surface temperatures. Each color represents a temperature increment of 8.33 K.



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(b) Lower surface.

Figure 10.- Concluded.

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16. Abstract

An interactive computer graphics technique known as the Graphic Display Data method has been developed to provide a convenient means for rapidly interpreting large amounts of surface design data. The display technique should prove valuable in such disciplines as aerodynamic analysis, structural analysis, and experimental data analysis. To demonstrate the system's features, an example is presented of the Graphic Data Display method used as an interpretive tool for radiation equilibrium temperature distributions over the surface of an aerodynamic vehicle. Color graphic displays were also examined as a logical extension of the technique to improve its clarity and to allow the presentation of greater detail in a single display.

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