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IMAGE PROCESSING OF AERODYNAMIC DATA

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SUMMARY

The use of digital image processing techniques in analyzing and evaluating
aerodynamic data is discussed. An image processing system that converts
images derived from digital data or from transparent film into black and
white, full color, or false color pictures is described. Applications to
black and white images of a model wing with a NACA 64-210 section in
simulated rain and to computed flow properties for transonic flow past a
NACA 0012 airfoil are presented. Image processing techniques are used to
visualize the variations of water film thicknesses on the wing model and to
illustrate the contours of computed Mach numbers for the flow past the NACA
0012 airfoil. Since the computed data for the NACA 0012 airfoil are available
only at discrete spatial locations, an interpolation method is used to provide
values of the Mach number over the entire field.

INTRODUCTION

Digital image processing, originally established to analyze and improve lunar
images, is rapidly finding a wealth of new applications in many areas. Such
applications include those in the field of medicine (e.g., tomography and
thermography), in earth resource analysis and planning (e.g., land usage and
minerals), in geophysical and seismic research, in nondestructive testing and
evaluation, as well as in industrial process control.

Recently, there has been interest in using image processing techniques to
analyze and evaluate aerodynamic data. Usually the analysis and evaluation of
aerodynamic data involves examining and summarizing physical measurements
and/or numeric data. In many cases, this is not the most efficient way of
obtaining the desired aerodynamic information.

Using digital image processing techniques, an easily-interpretable, optical
presentation of the data can be obtained. This is accomplished by
transforming aerodynamic data, derived from calculations or from print or
film, into a matrix of pixels (picture elements) with each pixel capable of
256 gray levels, thus requiring eight bits. When color is used as an output
medium for this monochrome imagery, certain features of the data are
highlighted and thus are identified easily. This technique, referred to as
pseudocolor, maps each of the gray levels of a monochrome image into an
assigned color and is done with the belief that the eye more usefully discerns
shades of color than shades of gray. With this technique, the mappings of the
colors are computationally simple and fast. This makes pseudocolor an
attractive technique for use on digital image processing systems that are
designed to be used interactively. It should be noted, however, that the

success or failure of a particular pseudocolor technique in analyzing images
depends upon the nature of the image. One property that has a noticeable
effect is the noise in images digitized from film or print. The human visual
system can filter out the high spatial frequency noise fairly well when the
intensity is affected. However, when the noise is converted to colors by
pseudocoloring operations that change colors at high rates (such as random
assignment) the image can be difficult, if not impossible to see. It becomes
very difficult to preceive features of interest unless the colors are assigned
systematically. On the other hand, random assignment of colors is an
attractive technique to present image data which are derived from calcula-
tions, since noise is not present in the image.

In this study, image processing has been used to study the effects of water
films on the aerodynamic properties of wing surfaces, and to provide a fast
and efficient method for presenting flow field properties such as Mach number
distributions obtained from numerical solutions of flow equations.

SYSTEM DESCRIPTION

An image processing system is the combination of an image processor, control
and display devices, and the software necessary to provide the capability to
analyze and enhance image data interactively. The system used in this study
consisted of a COMTAL Vision One/20 image processor with a monochrome video
camera, and a Hewlett Packard (HP 1000) minicomputer with disc and other
peripheral equipment. Figure 1 shows a block diagram of the system.

COMTAL Vision One/20

The COMTAL Vision One/20 is a real-time interactive image processor that may
be operated as a stand-alone system or as a peripheral unit of a host
computer. The processor produces high spatial resolution video images in full
color, in pseudocolor, or in shades of gray over a full range of brightness
from 0 (black) to 255 (white). It acquires these images from built-in image
generating functions, from the video camera or from the system interface,
which is the link between the host computer and the COMTAL system. The host
computer is used to enter digital image data (monochrome or color) into the
COMTAL Vision One/20 via the system interface, while images from film or print
are entered through the video camera as monochrome analog values and then
converted to digital data.

The COMTAL Vision One/20 consists of a fully integrated LSI-11 system
controller, image processing electronics, refresh memory using 16K RAM, and
application firmware. The LSI-11 system controller handles the switching and
the control of the images, manages the memory, and controls the overall COMTAL
system in response to operator commands locally via the keyboard control unit,
or remotely through the system interface. The LSI-11 utilizes a combination
of ROM and RAM to provide interactive control and processing. Additional RAM
is available for user-generated software. The operating system, furnished in
firmware (ROM), allows the user to interact with the system through a set of
high level commands that require only initial letters from the keyboard to
complete instruction definition (ref. 1).

2

All image data and graphic overlay data are stored in RAM refresh memories. The system has four 512 x 512 x 8 bit image memories with four 512 x 512 x 1 bit graphic memories which can be dynamically reconfigured to one 1024 x 1024 x 8 bit image with a single graphic plane. Image data retrieved from storage are processed by two independent, sequential processors, a function processor, and a pseudocolor processor. With the use of fast look-up tables, these processors perform analysis and enhancement algorithms on the data after it is retrieved from storage. Graphic overlay data can be retrieved from the refresh memory and presented to the display simultaneously with the retrieval and display of the image data. The graphic overlays, which are independent of each other and of the images as well, can be placed nondestructively over the image being displayed. Images and graphic overlays, as well as character input commands and output data, are displayed on a very high spatial resolution (512 x 512) color monitor.

For interactive modification of displayed process parameters, a manually operated trackball and a data tablet are available. These devices can also be used to position a target (another feature of the COMTAL system) to any pixel location on the display. This target which is programmable (shape and color) can also be controlled by software or firmware. The X and Y coordinates of the target are available through the standard system interface.

HP 1000 Computer

With the HP 1000 computer, disc and other peripherals, an orderly sequence of events for the entire processing system can be organized and controlled. As host to the COMTAL Vision One/20, the Hewlett Packard minicomputer is used to enter command data to the system, for image/graphic data transfers between the system and the original data source, for control of processing functions, and for implementing other application programs.

The operator communicates with the computer and its peripherals (disc, magnetic tapes, and printer/plotter) as well as with the COMTAL via a CRT terminal. Data files and application programs are stored on the disc while magnetic tape is used to store digital data. An electrostatic printer/plotter is used to obtain image data as well as intensity profiles (graphs) of images. Quick hard copies of displayed images and graphic overlays are obtainable with a hooded Polaroid camera. For better copies, Langley photographic services are used.

IMAGE PROCESSING OF WATER FILMS ON A WING SURFACE

In support of an intense nation-wide investigation into the effects of weather on aircraft performance, wind tunnel tests with simulated heavy rain were conducted by researchers from the Subsonic Aerodynamics Branch of the Low-Speed Aerodynamics Division of the NASA Langley Research Center. The effect of water collected on the wing surface is important because, in addition to adding weight, the water acts as a surface contaminant that may influence pressure gradients, skin friction drag, and boundary-layer characteristics and transition. All of these factors can influence lift and/or drag (ref. 2).

Tests were conducted in the 4-by-7 meter wind tunnel where water, containing a dye, was sprayed into the tunnel stream ahead of a model wing with a NACA 64-210 section (ref. 3). At various times, an ultraviolet strobe light was used to cause the dye to fluoresce. For changes of the wing configuration, angle of attack, or liquid water content, flow patterns on the model surface were recorded with overhead cameras using photographic transparent film. Images of these flow patterns were analyzed using the COMTAL image processing system. As analog input to the video camera, flow patterns recorded on the transparent film were converted to monochrome images in the COMTAL system. After being preprocessed to minimize noise transmission from the camera, each image was stored on the disc for subsequent analysis. After studying the intensity distribution of the images, the researcher selected, for each image, four pixel intensity ranges to represent variations of the water film thicknesses. With the hardware capabilities of the image processing system, each selected intensity range was classified in real time into a particular color. The resultant classified areas were instantly displayed on the monitor using pseudocolor presentation, with user selected colors assigned via the keyboard or through the system interface. In this vivid optical presentation of the flow pattern, each pseudocolor was associated with water film thicknesses as indicated on the transparencies. Actual discrete water film thickness measurements could not be determined for these images because of inadequate resolution in the photographs.

Figure 2 shows a flow pattern analyzed on the COMTAL system. In this pattern, the angle of attack of the wing with flaps down was 20° and the liquid water content was 20 gm/m^3. The darker regions represented the heavy water film thicknesses while the brighter areas represented the lighter thicknesses.

Also, intensity profiles of an X (horizontal) or Y (vertical) plane through any location on the image could be obtained. Figure 3 shows a typical X intensity profile of a flow pattern. The intensity profiles are displayed on the system's color monitor as graphic overlays or passed to the computer for output on the printer/plotter.

VISUALIZATION OF FLOW PAST A NACA 0012 AIRFOIL

Image processing techniques were used to help analyze and evaluate data obtained from numerical solutions of flow equations. In an aerodynamic study, inviscid flow past a NACA 0012 airfoil was computed. Researchers from the Loads and Aeroelasticity and the Transonic Aerodynamics Divisions at Langley and from the University of California, Los Angeles, used a modified version of the TAIR computer program (ref. 4) to generate numerical solutions of the conservative potential equation

$$\left(\rho\phi_x\right)_x + \left(\rho\phi_y\right)_y = 0 \tag{1}$$

where the density, ρ , is

$$\rho = \left[1 - \frac{\gamma - 1}{\gamma + 1}\left(\phi_x^2 + \phi_y^2\right)\right]^{\frac{1}{\gamma - 1}} \tag{2}$$

4

x and y are streamwise and lateral coordinate directions, ϕ is a velocity potential, and γ is the ratio of specific heats. Finite difference methods were used to solve equations (1) and (2) in a body-fitted coordinate system like that shown in figure 4. The system has 149 grid lines intersecting the airfoil and 30 grid lines around the airfoil. The innermost line around the airfoil defines the airfoil boundary. Mach number data obtained from this study were used to demonstrate the capability of using image processing techniques to analyze and evaluate such data.

For this application, an image file was created from the aerodynamic data by implementing a computer program that does the following:

    1. Converts the streamwise and lateral coordinate directions to pixel locations in a 512 x 512 array;

    2. Converts the values of the flow properties (Mach number or density) to gray scale values between 0 and 255; and

    3. Implements a linear interpolation method to provide values of the flow properties over the entire field (since the computed data were available only at discrete spatial locations).

Inputs to the program allow the operator to:

    1. Select the Mach number or density fields for evaluation; and

    2. Select the size of the flow field to view and the flow field for magnitude scaling.

For example, to zoom in on the field around the airfoil's leading edge and to provide good magnitude resolution, the operator could select the data field from the 10 innermost grid lines around the airfoil and from grid lines that intersect the airfoil within 10 percent of the chord of the leading edge.

The image file created from the program can be presented on the COMTAL display either as a monochrome image, with the various shades of gray representing different values of the flow field variables, or as a pseudocolor image, with the different colors forming contours of the computed flow quantities. Each presentation of the data can quickly be accomplished in 1/30 of a second by depressing one key on the COMTAL keyboard. In addition, the researcher can use the trackball to easily obtain, in real time, the most desirable color contrast for the presentation of the contours on the display monitor.

Figures 5 and 6 show images displayed on the COMTAL system using the Mach number values (derived from given and linearly interpolated data) under different conditions. Figure 5 shows images of the Mach numbers throughout the flow field for a free-stream Mach number (M_∞) of 0.63 and angle of attack (α) of $0°$. Figure 5a shows the Mach number values in shades of gray. The dark regions near the airfoil's leading and trailing edges indicate regions where the Mach numbers are low. The relatively bright areas around the forward half of the airfoil indicate expansion of the flow (increase in local Mach number). Recompression (decrease in Mach number) occurs over the aft

portion (where the gray shades are not as bright). Figure 5b shows the contours of the Mach number levels. The gradual spacing of the contours indicates that there are no discontinuities, such as shock waves, in the flow field. Figure 6a shows the gray image for M_∞ of 0.75 and α of 2^O. The bright area in the upper portion of the flow field indicates a large region of supersonic flow that is terminated by a shock wave on the upper surface of the airfoil. In figure 6b the shock is evident from the clustering of contour lines near midchord. This corresponds to the termination of the bright area in figure 6a.

CONCLUDING REMARKS

An image processing system has been described and the use of digital image processing techniques to enhance the display of aerodynamic data has been discussed. Monochrome imagery and pseudocolor techniques were used to visualize and indicate the water film thicknesses on a wing model with a NACA 64-210 section and to present the computed flow properties for transonic flow past a NACA 0012 airfoil. In evaluating the water films on the wing model, monochrome images derived from transparent film were examined and user-selected colors were assigned to represent different intensity ranges. The colors in this pseudocolor image represented different water film thicknesses on the wing surface.

In presenting the computed flow properties of transonic flow past a NACA 0012 airfoil, a monochrome image was derived from the computed flow values. The gray shades of this monochrome image represented values of the flow field variables while the colors (randomly assigned within the system) of the corresponding pseudocolor image represented the contours of the flow variables. Even though other methods (e.g., computer graphics) exist for displaying results such as the computed properties for flow past an airfoil, image processing techniques offer an alternative method that is both fast and efficient. This is due to the image processing system's software, built-in hardware, and interactive capability.

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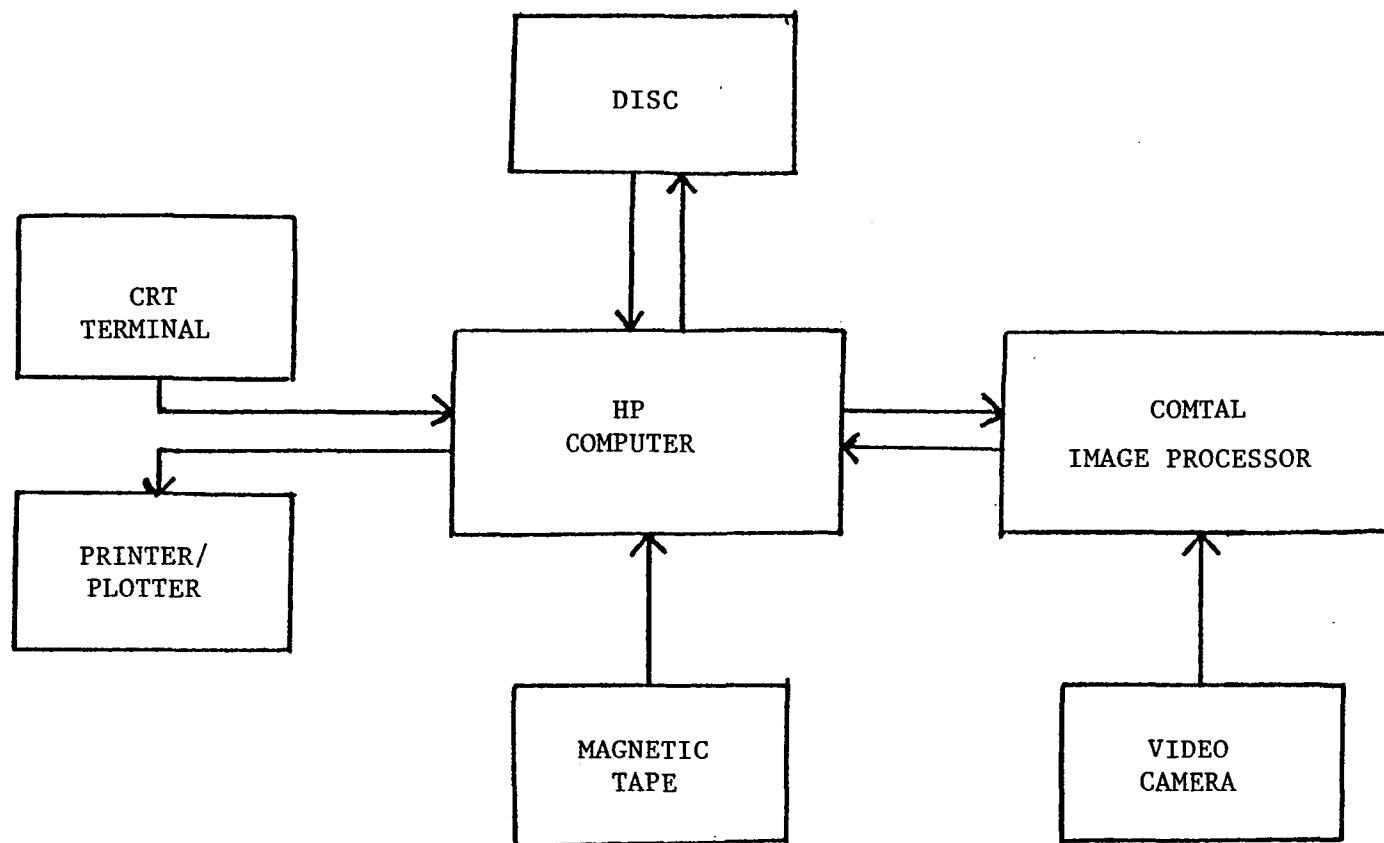
Figure 1. – Image Processing System Block Diagram
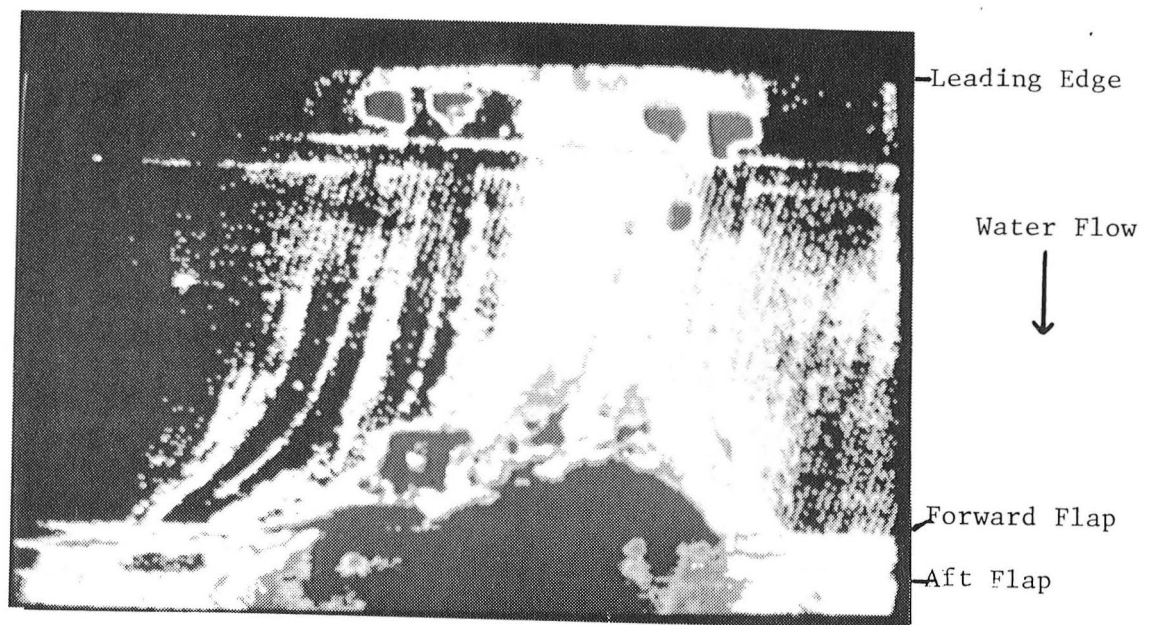
Figure 2. - Typical water film patterns on upper wing surface with flaps down, at angle of attack 20°, and liquid water content 20 gm/m³.
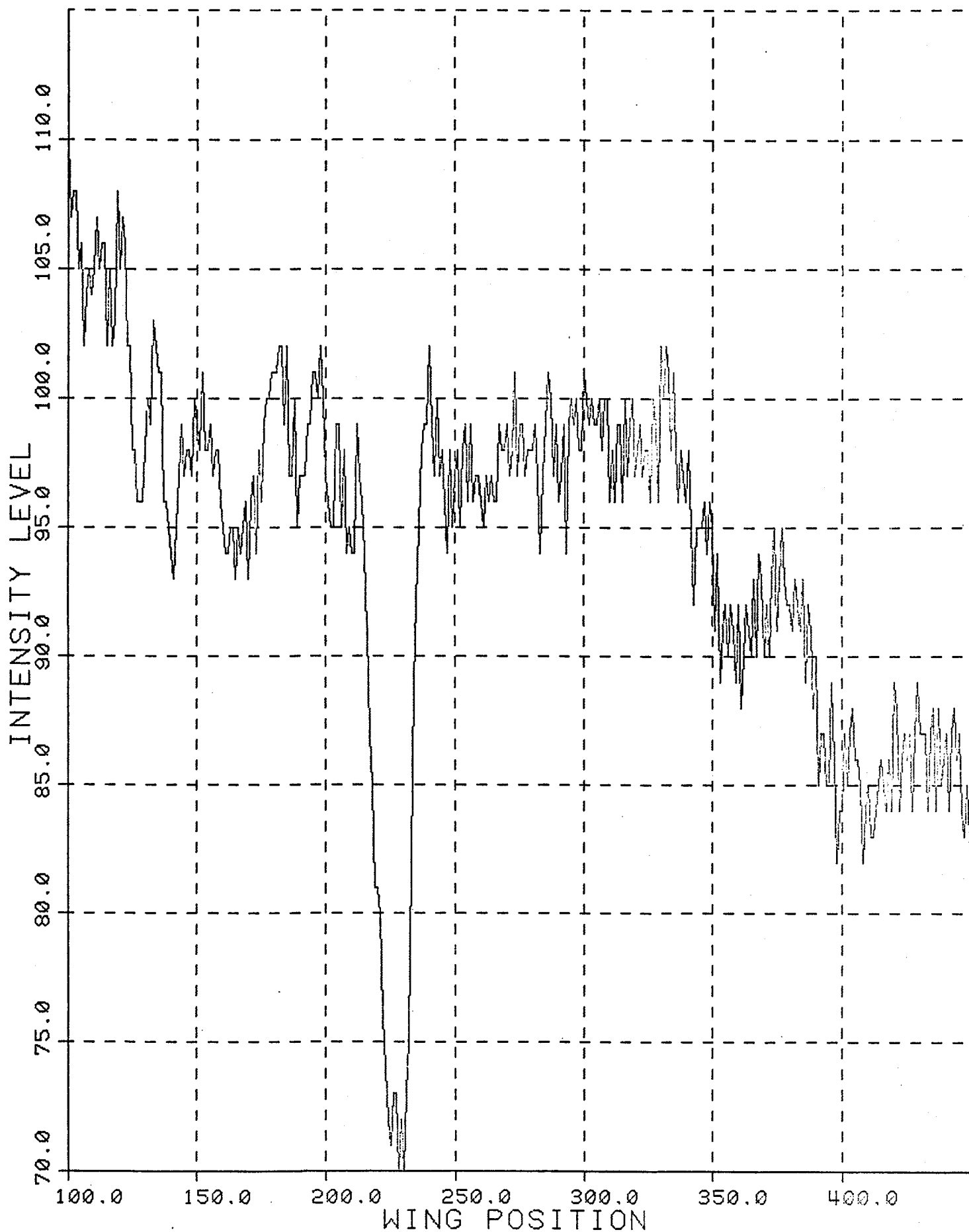
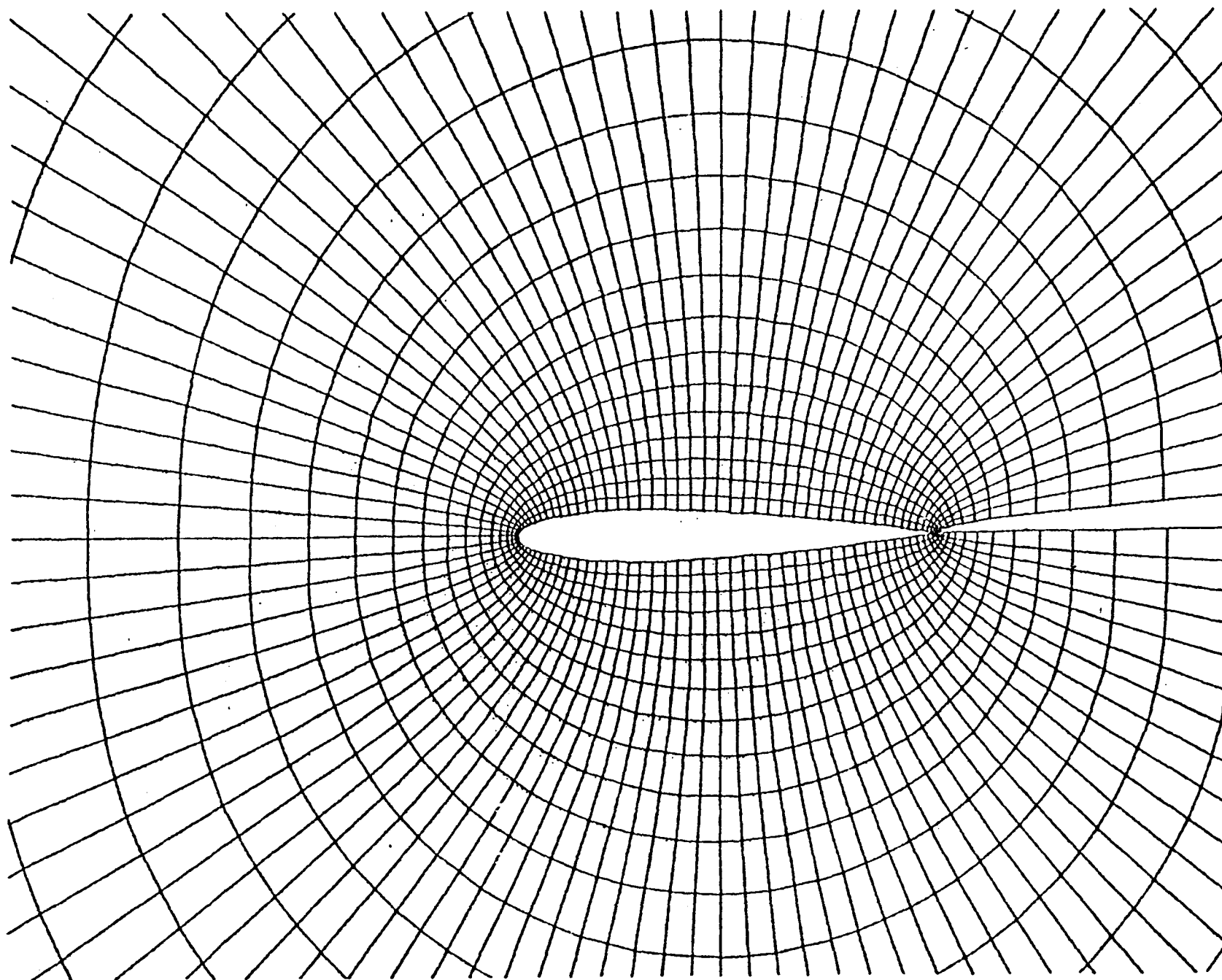Figure 3. – Film transmission as a function of chordwise position at one point along the length.
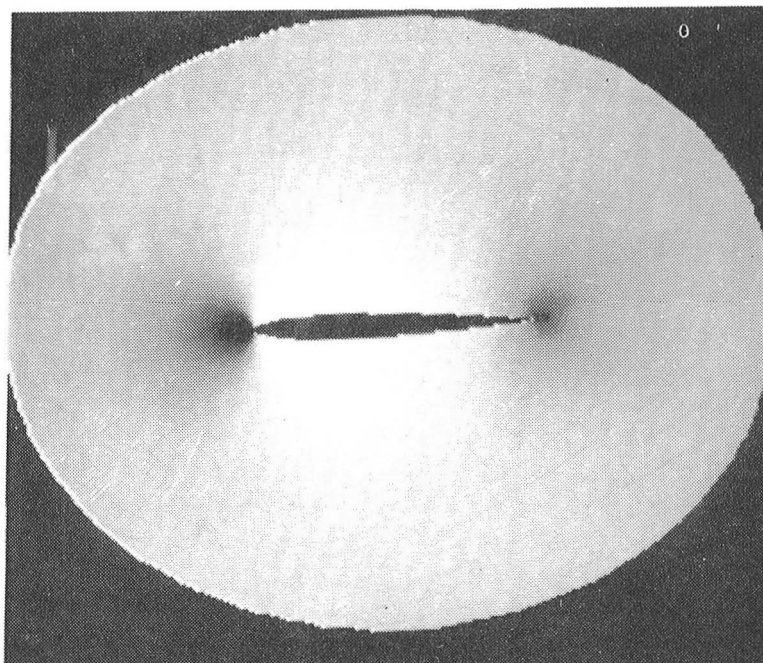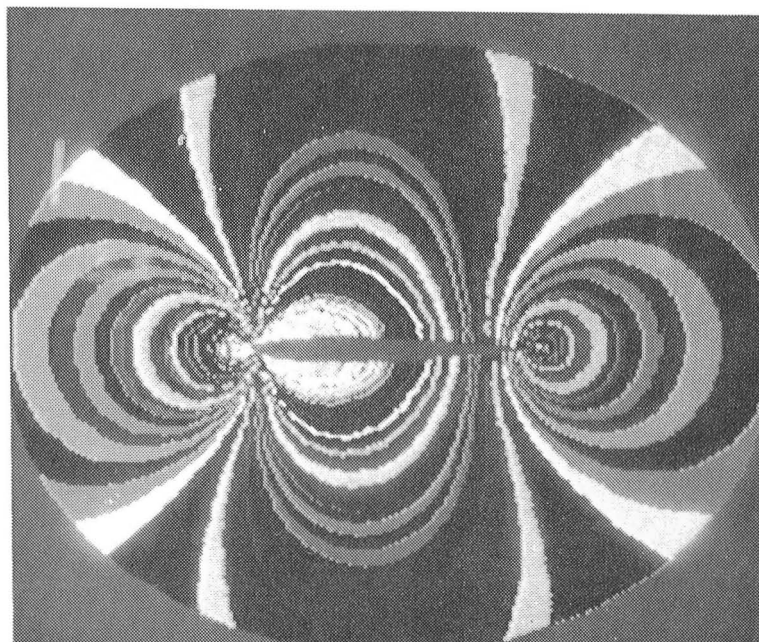
10

Figure 4. – Computational grid pattern for numerical solutions
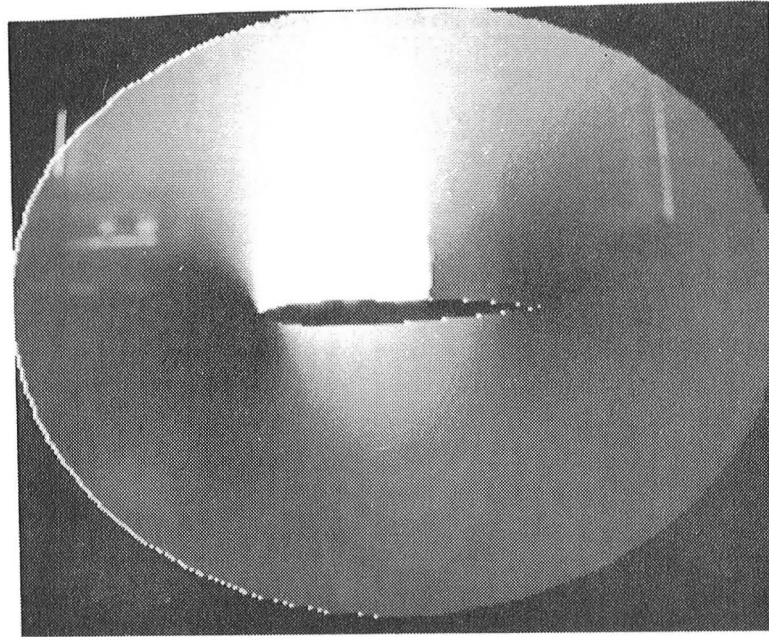to the flow equations; NACA 0012 airfoil.

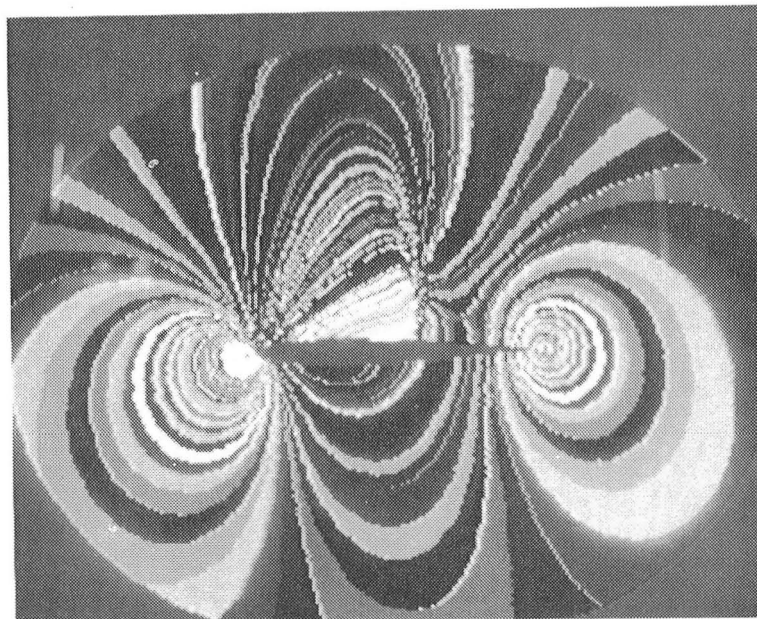(a) - Image in shades of gray for the Mach number data.

(b) - Image showing contours of the Mach number data.

Figure 5. - 512 x 512 images derived from actual and interpolated Mach number data for $M_\infty = 0.63$ and $\alpha = 0°$.

(a) Image in shades of gray for the Mach number data.

(b) Image showing contours of the Mach number data.

Figure 6. - 512 x 512 images derived from actual and interpolated Mach number data for $M_\infty = 0.75$ and $a = 2°$.

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16. Abstract

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