FINAL REPORT
SCAN CONVERTER
FEASIBILITY STUDY

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Contract NAS 9-3512

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Manned Space Flight Center
Houston, Texas

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TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

SECTION I

INTRODUCTION

This document is the final report of a four-month study under Contract NAS 9-3512 to the National Aeronautics and Space Administration (NASA) for a feasibility study of a scan conversion system employing a Litton-developed Electrostatic Image Recorder. The objective of this study was to demonstrate the feasibility of the Litton recorder for converting slow-scan Apollo television data to commercial television picture rates. The requirement to be fulfilled by an eventual scan conversion system is that of converting incoming 10-frame-per-second, 320-line-per-second, 525-line-per-frame video images for closed-circuit work or live broadcasts of Apollo television to the general public.

The study, performed during the period from September 9, 1964 to January 9, 1965, was based on results obtained from previous and continuing research and development (R & D) work funded by the Air Force and by the Data Systems Division (DSD) of Litton Industries. The study was augmented by the availability of a Litton-owned laboratory model recorder (Figure 1) that was modified to include the necessary characteristics for this application. In addition, concurrently with the NASA contract, Litton funded an independent electrostatic recording tube improvement program that provided advanced versions of the Litton Printapix ® tube.

The scan converter characteristics desired by NASA at the time of contract award were understood to be:

(1) Seven to ten levels of gray scale

(2) Continuous film operation at 10 frames per second

(3) Four to five hundred lines of resolution

(4) Indiscernible, frame-to-frame background shading

(5) Minimal noise

(6) Reusability

(7) Dry-process developing

The approach adopted by DSD in performing the desired conversion of television data from slow scan to commercial format was to modify the laboratory model Electrostatic Image Recorder to record the incoming 10-frame-per-second patterns on transparent film; develop the image by applying a pigmented, electrostatically charged powder; and subsequently project this image into a television camera utilizing a demonstration system (Figure 2).

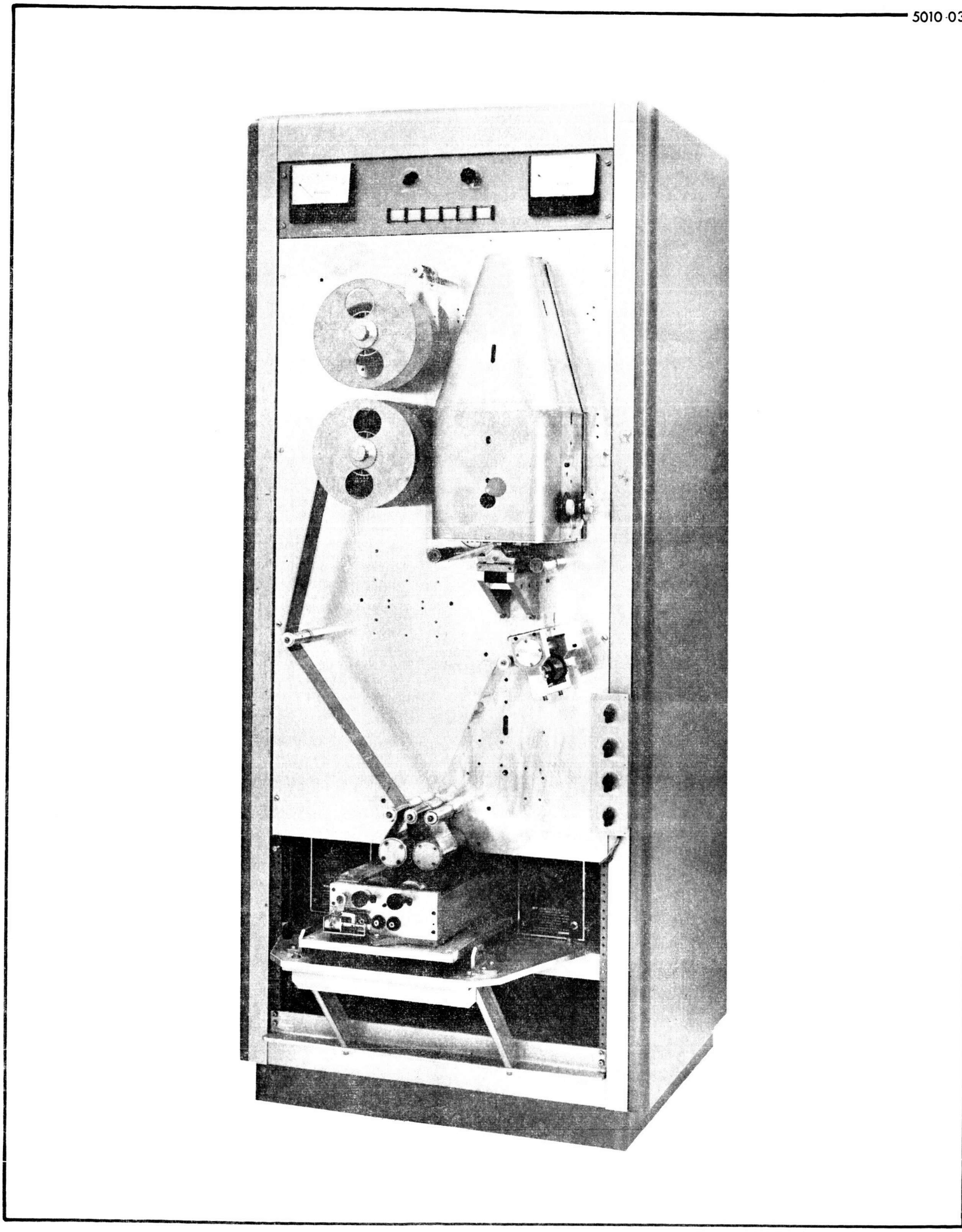

Figure 1. Laboratory Model Electrostatic Image Recorder

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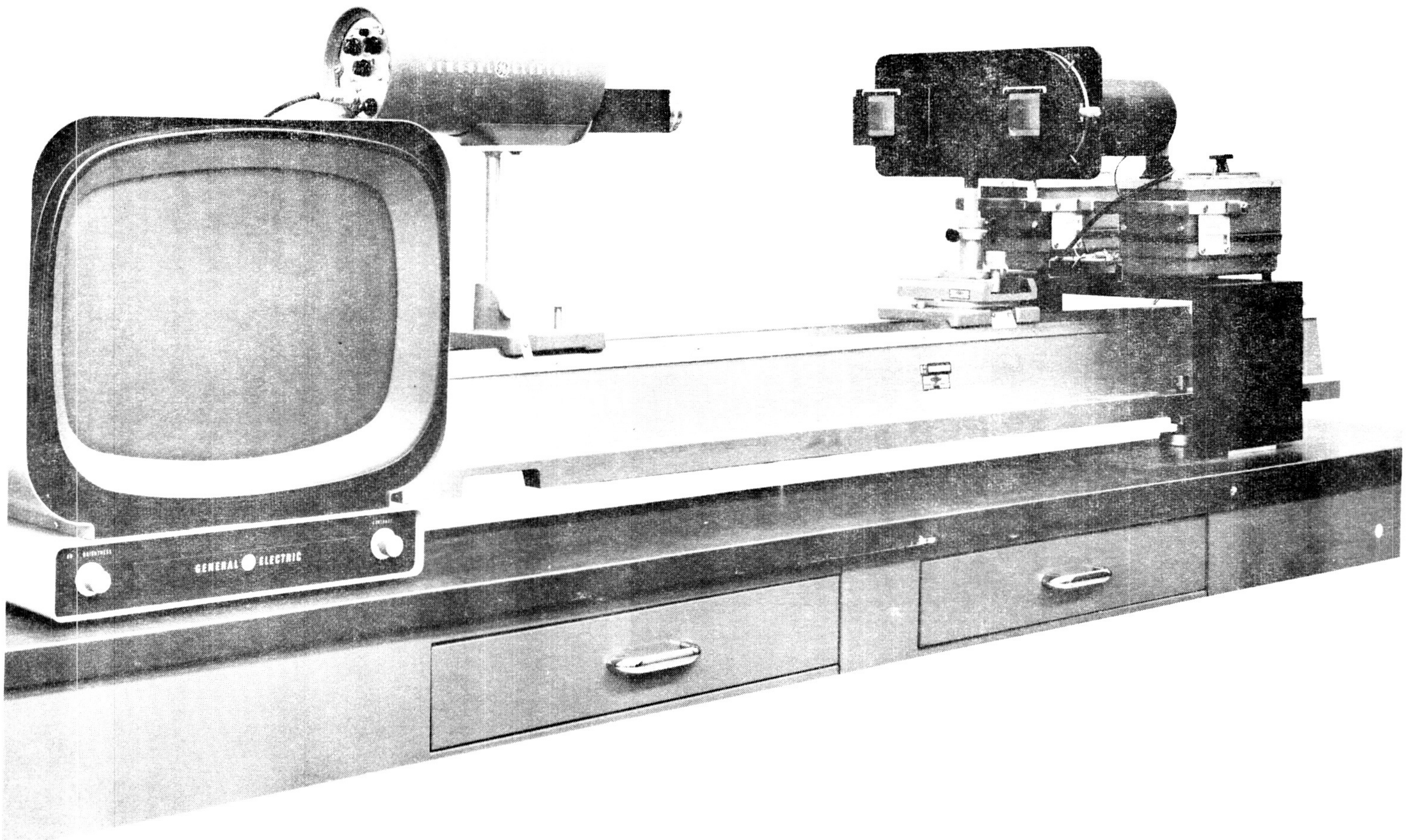

Figure 2. Scan Converter Demonstration System

SECTION II

STUDY RESULTS

2.1 SUMMARY

The objective of the study was to investigate the feasibility of using an electrostatic image recorder to convert Apollo television images to standard commercial television formats. The study was based upon results obtained on an Air Force program which involved the use of Litton-developed techniques of electrostatic recording and a unique Litton wire-array cathode-ray tube (Printapix ®). The three main areas of investigation were: resolution, frame-to-frame background shading, and the quality of gray-scale reproduction. Results of the study, including a demonstration of the modified laboratory model to NASA personnel, were highly successful in establishing the feasibility of the electrostatic recording technique. Acceptable qualities of resolution, background shading, and gray-scale reproduction were obtained. However, despite the improved recording characteristics demonstrated with the new Printapix ® tube, a degradation of picture quality was apparent during the demonstration.

An investigation of picture quality by Litton has led to the conclusion that the degradation resulted from the techniques employed in the construction of the R & D quality tubes. Litton firmly believes that by use of improved construction techniques, picture quality can be improved to an acceptable level.

2.2 DETAILED RESULTS

2.2.1 Recorder Operation at Ten Frames per Second

The laboratory recorder was modified to expose and develop film at ten frames per second. No problems were encountered in this operation.

2.2.2 Gray Scale

The best density achieved on transparent dielectric film was approximately 2.0. Ten to eleven, ($\sqrt{2}$), gray-scale steps were discernible.

2.2.3 Resolution

Resolution determined by the shrinking raster technique using a Litton-designed pattern generator was found to be 230 line-pairs per inch (9.1 line-pairs per millimeter) at 8.9-percent modulation. The resolution is not necessarily limited to this value in that the 230 line-pair performance was obtained at an interim point in the system improvement program. The theoretical limitation is set at 500 line-pairs per inch or 20 line-pairs per millimeter using present Printapix ® tubes.

2.2.4 Density Consistency

The density consistency was estimated to be within ±1/2 gray-scale step. The final uniformity was demonstrated by sequential flashing of images into a closed-circuit television system.

2.2.5 Vertical Streaking

While the parameters of resolution uniformity and gray-scale appeared to be satisfactory, quality was somewhat degraded by the presence of vertical streaks in the recordings. Careful analysis disclosed that these streaks were caused by conditions existing within the faceplate pin array of the Printapix ® cathode-ray tube (CRT). In consultation with the Litton Tube Division, two probable causes were isolated: (1) inaccurate winding of the pin array, resulting in pins being "shorted" together; and (2) smearing of pin ends as the result of the operations involved in faceplate fabrication. Although this condition has existed to some extent in previous tubes manufactured by the Tube Division, image degradation has been to a much lesser degree.

For instance, certain of the test recordings supplied to NASA as part of the demonstration of scan converter feasibility show a remarkable freedom from streaking. These recordings were made with the third experimental tube developed under company sponsorship.

2.2.6 Demonstration and Recording Samples

On January 21, 1965, a performance demonstration of the recorder was conducted for NASA personnel. In the areas outlined in the original proposal, the demonstration proved the feasibility of using an electrostatic recorder as a scan converter. Samples of the recording were supplied to the NASA representative.

SECTION III

RECOMMENDATIONS

3.1 INTRODUCTION

This section indicates for NASA's consideration Litton's recommendation for additional efforts on scan conversion techniques using an electrostatic image recorder. Based on the results of the present NASA feasibility study, the additional work would lead to the development of an engineering prototype scan converter system.

It is recognized, however, that any hardware program should be contingent on the demonstration of acceptable picture quality. In addition, several changes in requirements were introduced by NASA in the areas of format, frame rate, film reusability, and resolution. An investigation of picture quality and the revised requirements form the basis for Litton's recommendations for additional effort on this program.

Assuming that an eventual goal of this program is development of an engineering prototype scan conversion system utilizing electrostatic image recording techniques, Litton recommends that the following approach be taken.

3.1.1 Phase I

The present feasibility study should be considered as Phase I of the program.

3.1.2 Phase II

Phase II of this program should consist of a continuation of the present laboratory study at rates and resolution approaching NASA's present need of 0.625 frame per second and 1280 lines per frame. The rates should be chosen to be consistent with current Air Force rates of 1 frame per second and 1000 lines per frame. The follow-on study should concentrate on the demonstration of a high-resolution, uniform, half-tone recording of pattern generator output.

3.1.3 Phase III

Phase III of this program should be contingent upon the outcome of Phase II and should lead to the construction of an engineering prototype. This phase should include a pictorial simulator as an input, and a television camera as an output. The equipment should be thoroughly engineered for operation in the expected environment, with particular attention to maintenance and setup.

3.2 PHASE II EFFORT

3.2.1 Elimination of Vertical Streaks

During the demonstration of the scan converter system, a residual condition, referred to as streaking, was observed. This phenomenon consisted of vertical streaks in the data recording on the transparent dielectric film. This condition gives an appearance that is similar to that seen on a motion picture screen when the film has been scratched by passage through a defective film transport mechanism. The horizontal resolution of the recorded image was impaired by this phenomenon.

The problem of streaking phenomenon will be attacked by analyzing the Printapix ® CRT to determine the cause, specification of improvements, and evaluation of end results.

3.2.2 Demonstration of 1000-Line, 1-Frame-per-Second Recording

A new requirement has been outlined by NASA for a slow-scan, high-resolution scan converter. The specified parameters of 0.625 frames per second and 1280 lines per frame are sufficiently close to the presently available parameters of 1 frame per second and 1000 lines per frame so that further development is not required.

Demonstration of system performance under high-resolution conditions will be accomplished.

3.2.3 Demonstration of Performance and Ease of Setup with Accurate Capstan and Microscope

The present system has a 1/4-inch-diameter precision-ground rod as a recording platen. This nonrotating device causes scratches on the film and introduces flutter of the film in the recording aperture. Optimum alignment of the capstan and the Printapix® CRT has been impossible using this device. To achieve the 1000-line resolution, the completion of a large-diameter, rotating capstan is required. An interchangeable microscope unit is needed to facilitate tube alignment.

The improvement in resolution and image quality will be demonstrated after these items have been completed and installed.

3.2.4 Demonstration of Film Improvement

A problem presently exists with the experimental film being produced to Litton specification. Poor adhesion of the dielectric layer to the base substrate is being experienced. Further analysis, the subsequent specification of an improved film, and the evaluation of final product will be necessary.

3.2.5 Developer Improvement

Some improvement in image quality can be expected from modifications to the toner development unit. Anticipated changes would include the installation of scraper blades to form and flatten the toner material before applying it to the film. In addition, experiments to find the optimum placement, height, and angular orientation of the magnetic brushes should be conducted.

3.2.6 Electronics Improvements

Previous studies made for the Air Force, to obtain the maximum resolution, have shown a limitation imposed by the sampling nature of the Printapix® CRT beam sweeping across the faceplate pins. This limitation occurs at 1/2 the frequency generated by the beam as it sweeps at a given rate across a given number of pins. Unless a sharp cutoff filter is used to limit the video amplifier bandwidth to this maximum frequency, a form of distortion is introduced.

A suitable filter would be designed and incorporated to eliminate this distortion. The improvement will be demonstrated as part of the Phase II effort.

3.2.7 Optimization of Gamma Correction

The Printapix ® Electrostatic Recorder has an overall response characteristic that is not flat. This can be likened to the well-understood density-log exposure curves of silver halide photography. In the course of determining the gray-scale capability of the system, the general nature of the amplifier amplitude response correction (Gamma) required to provide uniform and equal steps of gray was determined (Figure 3). The toe correction of the curve is needed due to the nonlinear response of the Printapix ® CRT. The high-amplitude correction is needed due to the tendency of the film to saturate with both the charge and toner media. The exact correction is a function of many parameters and should be more thoroughly studied.

Adjustable features of the present gray-scale generator used in conjunction with the measurement of test recordings on a densitometer will permit this determination.

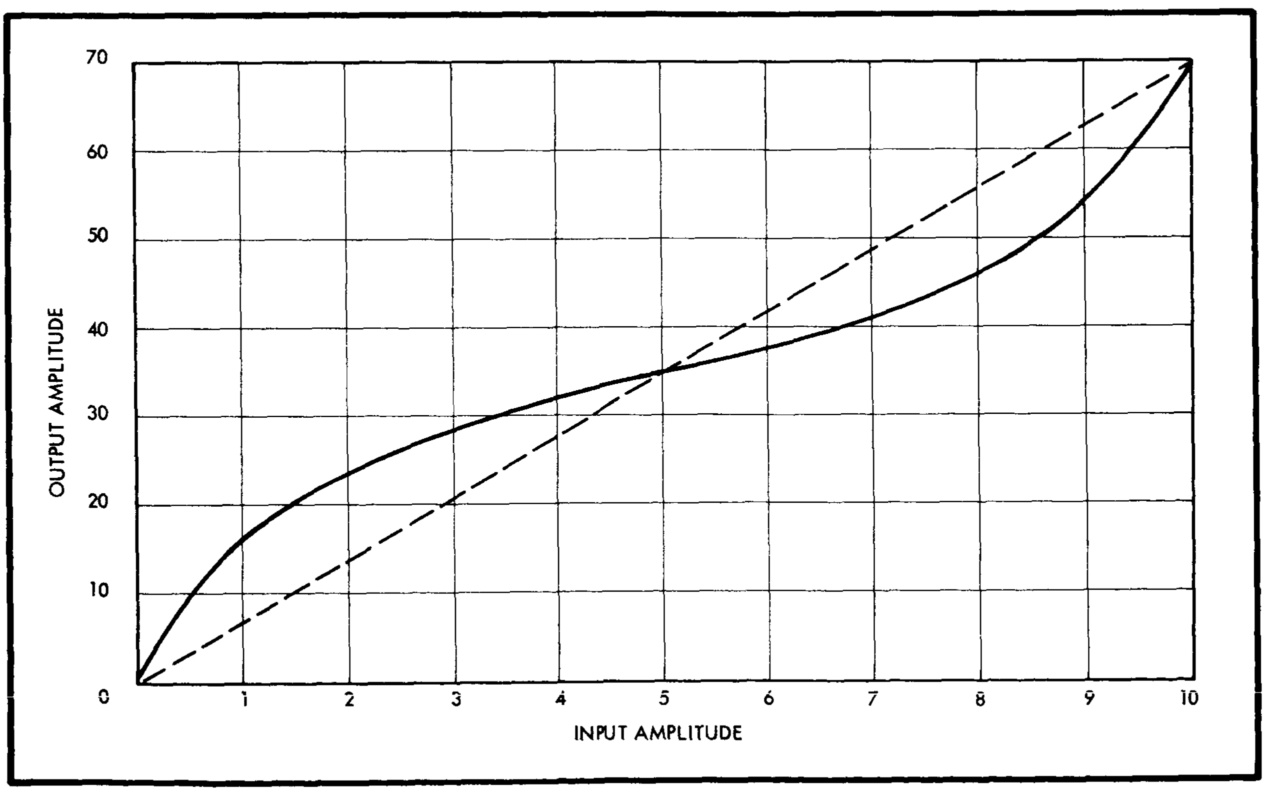

Figure 3. Relative Amplifier Amplitude Response Characteristics

3.3 PHASE III, DEVELOPMENT OF ENGINEERING PROTOTYPE

Based upon the successful completion of Phase II effort, the development of a complete working model is considered advisable. This engineering prototype would consist of the following:

(1) A pictorial simulator, either a flying-spot scanner or modified television camera.

(2) An electrostatic image recorder of similar design to the laboratory model now in existence at Litton Industries, Data Systems Division, except that synchronized sweep and film motion would be incorporated.

(3) An exposure film gate using a synchronized flash lamp source.

(4) A television camera to accept the image from the film gate.

(5) A television monitor to view the final results.

The usual reports and a set of preliminary drawings would be submitted as a climax to the Phase III program.

SECTION IV

TECHNICAL REVIEW

4.1 INTRODUCTION

This section of the report delineates the procedural development of the study. It is to be noted that a study program for the Air Force to investigate methods of improving the performance of electrostatic image recording was being performed concurrently with the NASA study. While the Air Force study was directed toward increased resolution at slower frame rates, many of the results are applicable to improved gray-scale recording. Whenever possible the data was applied to augment the NASA study effort. In addition, Litton funded outside both the NASA and Air Force contracts a Printapix® tube improvement program directed toward obtaining maximum performance of the tubes. Wherever possible, the most advanced tube was employed. The results of the study have been summarized in Section II and will not be repeated here.

4.2 PREPARATION FOR TESTS AND DEMONSTRATION

4.2.1 Transport Mechanism

The recorder transport mechanism remained basically unchanged. A variable speed drive motor allowing operation at 10 frames per second (0.32 inch per second) was installed. Additional film guides and the substitution of a precision ground rod for the original capstan was accomplished. With these changes, the film could be precisely transferred from the supply reel, past the Printapix® CRT and the developer station, to the take-up reel.

4.2.2 Recording Tube Mount

A highly precise Printapix® CRT mount was designed, built, and installed. This unit has micropositioners for the yoke and focus coil, centering magnets, high-voltage isolation, magnetic shielding, and precision gap-adjustment devices.

4.2.3 Printapix ® CRT

Through the efforts of a Litton-sponsored development program, an advanced design Printapix ® CRT was used on this program. The features of this tube included a flat faceplate, a high-resolution electron gun, and an improved recording pin array. Using this tube, improved image quality and resolution were obtained. The new Printapix ® CRT was delivered late in the study program, and additional work remains to be done on the tube to eliminate some short circuiting of pins in the recording array.

4.2.4 Magnetic Developer

In the course of a study of developing techniques for the U.S. Air Force, a commercially available magnetic brush developer unit was observed in operation. The high quality of developed image produced by this unit led to its purchase for use on the scan converter. The unit was adapted to operate at the proper speed for scan conversion, resulting in a considerable saving of design time.

4.2.5 Electronics

A number of modifications were made in the basic recorder to permit operation at the scan converter rate of 320 lines per frame, 10 frames per second. These were (1) design of new sweep generator cards to operate at 3200 cycles per second, (2) design of a dynamic focus circuit, (3) design of a wider bandwidth video amplifier, (4) design of a constant current focus supply, and (5) design of a motor control circuit for the new developer.

4.2.6 Pattern Generator Modification

An existing pattern generator (or simulator) capable of delivering a synchronizing pulse at 1000 cycles per second and a range of video output pulse varying from 1 megacycle to 1 cycle per second was modified for this program. A new synchronizing output at 3200 cycles per second was derived. With this unit, a measure of scan converter resolution was obtained by drawing horizontal and vertical lines to the limit of system definition.

4.2.7 Gray-Scale Generator

A new generator was designed on this program to permit gray-scale determination. The device is essentially a four-place binary counter with a resistor ladder network in its output (digilog). The unit was set to produce 10 steps of gray plus zero by an appropriate reset. Each resistor was made adjustable so that the 10 steps could be individually adjusted.

The unit was calibrated so that each step produced approximately one $\sqrt{2}$ gray-scale change on the final recording.

4.2.8 Flash Exposure Station

To adequately demonstrate freedom from frame-to-frame background fluctuations, an output simulator was designed on this program. It consisted of a standard closed-circuit television camera and monitor plus a synchronized flash exposure station. To simulate the effect of film being pulled into an exposure gate by a 10-frame-per-second intermittent movement, two sequential frames of film were cut and mounted before two strobe light units. A common optical system imaged both slides on the target of the television camera vidicon tube. A special synchronizing circuit attached to the camera caused each strobe light to be sequentially flashed six times in succession at the camera vertical rate of 60 fields per second. The lamps were alternated at a 10-cycle-per-second rate, simulating the film pull-down rate. The composite picture was observed on the television monitor to determine the degree of flicker.

4.2.9 Recording Materials

Transparent dielectric film was procured for use on this program. This film consisted of a laminate of base material 5-mils thick, a transparent conductive material, and a recording coating of approximately 0.2 mil. Recording paper was procured consisting of a conductive paper on which was placed a thin layer of dielectric. Both recording mediums were used on this program.