CR-73457

Vellum copy
O.K.

2-55535

CR 73457
AVAILABLE TO THE PUBLIC

Final Report *April 1970*

A STUDY OF THE MEANS OF INCREASING THE DYNAMIC RANGE OF VISUAL SIMULATION BY MEANS OF A FLYING-SPOT SCANNER

By: ALFRED E. BRAIN

Prepared for:

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
AMES RESEARCH CENTER
MOFFETT FIELD, CALIFORNIA 94035

CONTRACT NAS2-5535

SRI PROJECT 8031

Approved by:

DAVID R. BROWN, *Director*
Information Science Laboratory

TORBEN MEISLING, *Executive Director*
Information Science and Engineering Division

Copy No. ....

CR-73457

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
AMES RESEARCH CENTER
MOFFETT FIELD, CALIFORNIA 94035

REPLY TO ATTN OF: NAS 2-5535
AT:241-12

June 18, 1970

NASA Representative
Scientific & Technical Information Facility
P.O. Box 33
College Park, Maryland 20740

Subject: Transmittal of Contractor Report: "A Study of the Means of Increasing the Dynamic Range of Visual Simulation by Means of a Flying-Spot Scanner" by Alfred E. Brain, Stanford Research Institute, Menlo Park, California.

Reference: Program Code 721-05-10-01

The subject report prepared under Contract NAS 2-5535 has been reviewed at Ames and is recommended for release in STAR as CR 73457.

Richard F. Claeys
Administrative Specialist
Technical Information Division

Enclosure: 1 cy subject report

cc: NASA Hqrs., Code USI (w/o encs.)

PRECEDING PAGE BLANK NOT FILMED.

CONTENTS

ABSTRACT ii

LIST OF ILLUSTRATIONS iv

I THE FLYING-SPOT SCANNER AS AN INPUT DEVICE FOR FLIGHT SIMULATORS 1

A. Provision of Basic Functions 1

B. Resolving Power 1

1. Lens Resolution 2

2. Film Resolution 2

3. Scanner Resolution 3

4. Recommended Improvement in Design 5

II REVIEW OF PERFORMANCE OF DALTO 2H53 FLIGHT SIMULATOR . . . 6

A. Scope 6

B. Rendering Equipment Operational and Setting Up . . . 6

C. Resolution 8

D. Suggested Modification 9

III CONVERSION OF 2H53 TO USE A 525-LINE COLOR MONITOR 11

IV POTENTIAL USE OF 2H53 FOR THE RANGE 1,000 to 10,000 FEET . 13

V PERFORMANCE OF THE MECHANICAL X, Y, θ SYSTEMS 15

VI RECOMMENDATIONS 17

ILLUSTRATIONS

1 Carrier Deck, Showing Asymmetry in the Sweep Circuit 8

2 Output from Azimuth Tachometer After Impulse Equivalent to 21-Degree Rotation--Time Axis 0.5 s/cm 16

I THE FLYING-SPOT SCANNER AS AN IN INPUT DEVICE FOR FLIGHT SIMULATORS

A. Provision of Basic Functions

The flying-spot scanner provides a convenient mechanism for generating television-type video signals appropriate for use in flight trainers. Since the basic pictorial information is contained in a photographic plate rather than a physical model, it allows great flexibility both in the choice of terrain and its scale. On the other hand, the fact that the data on the plate is a plan view means that it is impossible to provide any representation of height perspective for mountains or structures on the ground, such as control towers, that are significant when the aircraft is close to landing.

In the 2H53 Dalto equipment the photographic plate is attached to a carriage having X and Y motions to provide for displacement of the aircraft relative to the runway. The flying-spot tube rotates about an offset axis, satisfying the requirements for a forward view and the ability to modify the orientation of the aircraft. Perspective is created by hyperbolic distortion of the scanned patch on the flying-spot tube face, while pitch and roll are generated by tilting the projector and rotating the projector deflection coils. Thus all of the basic motions of the aircraft are provided for. In the Dalto equipment three photomultipliers and dichroic mirrors provide for the generation of a color signal.

B. Resolving Power

One of the inherent limitations of the flying-spot scanner as an input device for flight simulators is its marginal resolving power.

This limitation has three causes:

(1) The ability of the aerial camera lens to resolve the desired detail

(2) The ability of the film to record the detail on the photographic plate

(3) The ability of the scanner to generate an output signal modulated by the finest detail on the plate.

1. Lens Resolution

Assuming that the pictorial data is to be recorded by the aerial camera on the photographic plate as a single image, the maximum number of picture elements that can be recorded by a lens is usually estimated at $\sim 2.10^8$. However the performance of reconnaissance lenses has improved substantially in the last decade and the 24" f5.6 Paxar Delta lens made by Pacific Optical Company is stated to provide 86 lines/mm over a 9" X 9" plate, equivalent to 16.10^8 elements. Unfortunately, its spectral range is only from 546 to 656 mm--i.e., green, yellow, orange, and red, but minus blue. It is usual to eliminate the blue atmospheric haze from aero-photographs by using a K2 or #15(G) Wratten filter. Since the dispersion of glasses tends to become much larger toward the blue end of the spectrum, it is to be anticipated that a lens to provide full coverage of the visible spectrum would be relatively inferior in resolution.

2. Film Resolution

The 86 lines/mm for the above lens was recorded on SO-213 film using D-76 developer. This is very high film resolution in terms of conventional handling, and 40 lines/mm is more likely under field conditions with low-contrast subjects and local overexposure causing image spread. If color film is used with full spectral range there will be further loss, so that perhaps 30 lines/mm would be a practically realizable estimate, giving 2.10^8 elements on a 9" x 9" film--assuming that 30 lines/mm resolution is equivalent to resolving 60 picture elements per mm.

3. <u>Scanner Resolution</u>

Having provided 30 lines/mm on the photographic plate we now have the problem of reading it back with the flying-spot scanner. A projection cathode-ray tube will have upwards of 2,000 spot diameters across the tube face, the spot size being a function of both the high voltage supplied to the final anode, and the beam current. The energy in the beam determines the spot brightness and hence the signal level, which in turn affects the signal-to-noise ratio of the video signal giving rise to the output display. By raising the voltage on the final anode of the projection tube the spot diameter is reduced and the output signal increased; unfortunately since the beam is "stiffer" there must be a corresponding increase in sweep current. In general, the practical limit to reducing spot size is set by the power available for the horizontal sweep. Another factor of some significance in very finely focused beams is phosphor noise due to grain structure in the phosphor, its inhomogeneity of composition, and unevenness of deposit on the tube face.

Under normal circumstances it is to be anticipated that a projection tube could provide resolution equivalent to 5,000 spot diameters as a practical upper bound. However, in the present application, which makes use of appreciable hyperbolic scan distortion, the scanning driver can only be used at its full capability on peaks so that the useful projection-tube resolution is approximately halved. This gives 2,500 spot diameters across the tube face, which is compatible with the 525-line television image and the fact that in general the sweep extends across only about one-fifth of the tube face.

For the 5AZP24 projection tube, having a 5-inch-diameter tube face, the spot diameter is ~2 mil or 1/20 mm. If a unity magnification optical system is used as in the 2H53, the effective tube resolution is 10 lines/mm. Since the pictorial data is recorded on the photographic plate at 30 lines/mm, it is not possible with 1:1 optics to resolve the fine detail, and the resolution of the whole equipment is limited entirely by the cathode-ray-tube spot size. This very substantial sacrifice of resolution is necessitated by the need to sweep the scanning spot over a wide area when the plane is flying at maximum altitude--in this case 1,000 ft. It would be reasonable to use 3:1 demagnification to reduce the scanning-spot size on the film to be compatible with 30 lines/mm resolution, but then the desired ground coverage could not be achieved owing to the limited tube-face area and the limited sweep current to drive the scanning coils. Thus the use of 1:1 optics restricts the maximum resolution to the equivalent of 150 TV lines. However, even this resolution is not preserved at low altitudes. Assume that the near field of view (W) on approach = 300 ft, and the scale S of the photographic plate is 1:24,000; with 1:1 optics, if the spot diameter d = 0.002", the number of picture elements N across the width of the field is given by

$$N = \frac{W.S}{d} = (12.300)\left(\frac{1}{24,000}\right)\left(\frac{1000}{2}\right) = 75$$

Thus as the pilot approaches the runway the apparent quality of ground detail does not improve, and an important visual clue defining the height of the aircraft is lacking.

4. Recommended Improvement in Design

The way around this difficulty is to use a zoom lens for height variation, since the size of the scanning spot on the film plane can then be varied roughly* in proportion to the degree of zoom. It is possible to obtain zoom lenses with magnification ratios of up to 10:1. The scale change could be made a function of two variables, (1) the size of the scanned patch on the tube face, and (2) the degree of zoom, thus extending the effective dynamic range and preserving more of the detail that is recorded on the photographic plate.

---

* The resolution of zoom lenses is not quite as good as that of normal lenses of the same focal length, and varies considerably in performance over the zoom range.

II REVIEW OF PERFORMANCE OF DALTO 2H53 FLIGHT SIMULATOR

A. Scope

This section is concerned only with Units 2 and 4 and parts of Unit 3 of the Dalto 2H53 Flight Trainer, and is directed toward evaluating its suitability for the generation of pictures on a standard 525-line color monitor. Unit 2 is the Flying-Spot Scanner and Computer Enclosure, Unit 4 is the Control Console, and Unit 3 is the Projection Enclosure. The only parts of Unit 3 that were relevant to this evaluation were the Sync Generator 3A8, the ±20 volt Power Supply 3A6, the complete cable assembly shown in Figure 10-27 in the manual, and the frequency converter 3A5 for generating 400-cps power from the 60-cps power line. The 2H53 equipment uses vacuum tubes and transistors in approximately equal quantities, and the 3A6 Power Supply in the Projection Enclosure provides power for transistors throughout the whole system.

B. Rendering Equipment Operational and Setting Up

The manual NAVEXOS P-2603 is generally adequate in regard to circuit and wiring diagrams. Unfortunately in several instances the wiring diagrams did not conform to the labelling on the units. The worst errors have to do with the coaxial cables coming to the main frame and carrying the synchronizing pulses. In Figure 10-2, Unit 2 wiring diagram, the 2J10 horizontal drive goes to 3J2 instead of 3J9, and the 2J20 composite blanking goes to 3J6 instead of 3J10.

The reliability of the hardware has been consistent with what one might expect from equipment using vacuum tubes and relatively absolete types of transistors, except for the behavior of the Flying Spot Scanner Deflection Chassis 2A10.

Before attempting to set up Chassis 2A10, the following components should be checked to determine that they are not burned out:

(1) Grid Resistors R4, R5, R8, R9, R12, R13, R16, R17, R33, R34, R43, R44. All should be 100 ohms, 1/2 watt.

(2) Cathode Resistors R6, R7, R10, R11, R14, R15, R18, R19, R35, R36, R45, R46. All should be 22 ohms, 2 watt.

(3) Tubes V_1, V_2, V_3, V_4, V_7, V_8 (both halves of each).

The factor determining the general unreliability of this panel is parasitic oscillations in the six tubes, type 6336A, which are high-slope double triodes that behave as tuned-grid tuned-plate oscillators at frequencies in the vicinity of 100 MHZ. This problem was cured by putting a high-loss ferrite core over each grid lead, right at the tube socket. In setting up from a considerably maladjusted condition, Fuse F1 and Transistor Q1 (2N 1908) are likely to be wiped out; caution is necessary in setting the width control R2 and the base drive control R75. The output waveform shown in the manual as appearing at J3 is a very idealized representation, by comparison with what one sees using a Tektronix current probe on the output lead at Terminal M on J3. However, the waveform drawing does exhibit a significant defect in the performance of this panel--the modulated hyperbolic waveform does not have perfect bilateral symmetry, the amplitude in the positive and negative directions differing by about 20%. Thus when an aircraft is landing on a carrier deck the trapezium formed by the deck markings is unsymmetrical (Figure 1). Since perspective vision clues determine when

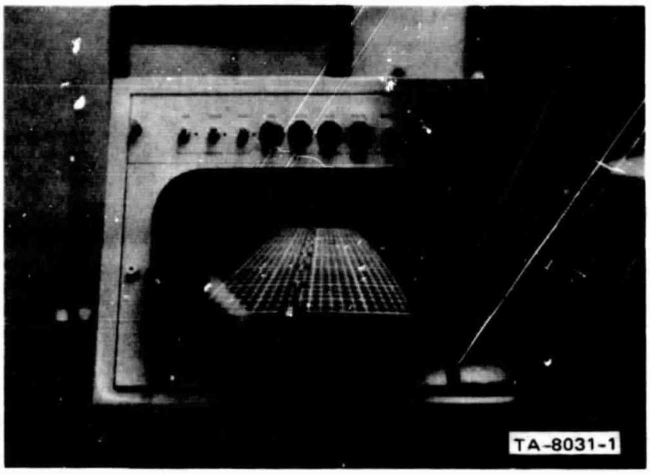

FIGURE 1 CARRIER DECK, SHOWING ASYMMETRY INHERENT IN THE SWEEP CIRCUIT

the aircraft is correctly lined up with respect to the runway and the pilot cannot center himself with respect to the displayed representation, this defect is considered to be of more than academic interest.

C. Resolution

The 150-mm f/2.8 Xenotar lens is operated at close to unity magnification. At exactly 1:1, moving the lens changes the magnification but the system stays in focus--or out of focus if not accurately set up. Thus, to set up the optical system in the flying-spot scanner, the lens should be put in the center of its focusing range and the focusing adjustment performed by moving the face of the flying-spot scanner tube 5AZP4. At the same time, the spot on the 5AZP4 must be optimized by adjustment of the focus control on the high-voltage power supply 2A7. It is evident that under low-level and landing-approach conditions the resolution of the television image is determined almost entirely by the spot size on the tube face. The 5-inch tube face is likely to be equivalent to ~2000 spot diameters, so that the spot size is ~2.5 mil, or

0.08 mm. Since the optical system is 1:1, this is also the size of the scanning spot on the film--i.e., there are approximately 12 picture elements per mm. The observed limiting resolution is close to 10 lines/mm. If the scale of the film image is 1000 feet per inch, the least resolvable ground detail will have a size of 2.5 ft. When the width of the field of view is 1500 ft, the spot size is compatible with the potential resolution of a 525-line system, but if it is only 250 ft, as the plane approaches the end of the runway, the apparent lack of resolution in the TV image is due entirely to the equivalent 2-1/2-ft-wide scanning spot. However, since apparent ground motion obliterates the detail too, the importance of this limitation is somewhat discounted. At a scale of 1000 ft per inch the available ground area in the present equipment would be 3000 by 8000 ft. The resolving power for both the film and the lens is in excess of 30 lines/mm so that their influence on the overall performance is negligible when compared with effects due to the scanning spot.

D. Suggested Modification

If the system is left as presently constructed, the only way to increase its resolution is to provide a smaller scanning spot. The spot can be made smaller by reducing the beam current, but this reduces the light output from the phosphor and hence the output from the photomultipliers. The existing arrangement does not give a noise-free picture, and the noise that is visible is photon noise rather than photomultiplier dark current noise--i.e., it is due to the discontinuous nature of the electron beam in the flying-spot tube and the lack of homogeneity in the phosphor being bombarded by the beam. Thus, lowering the beam current in the 5AZP24 would make the signal-to-noise ratio worse. A better solution would be to raise the final anode voltage and use a more modern projection tube, although this would entail an increase in scanning power and replacement of the Scanner Deflection Chassis 2A10. Since the 2A10 chassis has problems that have already been dealt with, replacement of this unit is worthy of consideration. However, if higher sweep power were provided it might become necessary to provide greater insulation for the horizontal sweep coils. The Dalto equipment in operation at N.A.S.A., Flight Research Center, Edwards, is presently using an improved scanner deflection chassis made by Litton Industries of San Carlos.

III CONVERSION OF 2H53 TO USE A 525-LINE COLOR MONITOR

The question has been raised as to the possibility of using a standard 525-line color monitor for the output display rather than the projection system made by Dalto. It must be understood that the pitch and roll functions in the display are provided by motion of the projection system, and that if the video signals are used in their existing form these operational functions will be absent from the picture displayed on the monitor. Possibly roll might be provided by rotating the sweep coils in the monitor.

Since the duration of a scanning line in the 2H53 equipment is 63.5 μs (see Page 7-4 of the manual) the horizontal sweep circuits do not require modification because the horizontal sweep time for 525-line television is also 63.5 μs. However, the aspect ratio of a standard television picture is 4:3, whereas in the 2H53 the aspect ratio is 3:1.

The 2H53 contains three photomultipliers feeding the red, green, and blue channels; since the phosphor on the 5AZP24 flying-spot tube is white and the photomultipliers are illuminated by dichroic mirrors, <u>simultaneous</u> signals are available at the outputs of Amplifiers 2A23, 2A24, and 2A25 even though the red, green and blue fields displayed by the projection system are <u>sequential</u>.

The vertical deflection coils in the scanner provide 60 sweeps per second, 20 for each color, and thus the vertical sweep rate is compatible, except that the lines are not interlaced. Thus the end product obtained by using the existing horizontal and vertical synchronizing pulses with a standard color monitor is a 262-line 60-frame sequential picture with 3:1 aspect ratio. Although sufficient gain is available to drive a monitor directly from the video outputs of 2A23, 2A24, and 2A25, unfortunately this causes overloading on the control monitor in Unit 4. It is recommended that a small video amplifier with about 20 dB gain be inserted ahead of each color input lead to the color monitor. A 6217 photomultiplier is used for the red channel rather than the 6219 used for blue and green, but even so the gain in the red channel was found to be somewhat down, and marginal even at maximum.

IV POTENTIAL USE OF 2H53 FOR THE RANGE 1,000 TO 10,000 FT

One suggested application of the 2H53 equipment has been to provide a simulator for planes flying at heights of 1,000 to 5,000 ft rather than for the range 0 to 1,000 ft for which it was designed. It is presumed that the scanning waveforms can be generated without too much difficulty, and that the carriage bearing the film will move over its available travel of 8 by 8 inches rather than the 8 by 3 inches as presently set up. Let us assume that an improved scanner tube is provided giving a 2-mil spot, and that the film scale is 10,000 ft/inch rather than the 1,000 ft/inch used previously. Let us also assume that we use a 5 to 1 zoom lens to provide height variation.

At 10,000 ft/inch scale, 1 mm on the film ≡ 400 ft on the ground, and if the minimum-size detail visible on the ground from 1,000 ft is 5 ft, the film has to carry a resolution of 40 lines/mm. This is a practical upper bound.

The 2H53 uses a 12° offset angle between the center of the tube face and the lens axis so that the lens resolution must be compatible with 40 lines/mm film resolution at 12° off-axis on the average, or 24° off-axis at worst. However, as we have seen in the previous discussion on lens resolution, as the focal length is varied the total number of picture elements per field tends to stay constant (at least as an upper bound), which is equivalent to saying that the off-axis resolution in lines/mm varies inversely as the focal length of the lens. Practical experience indicates that for a zoom lens to achieve 40 lines/mm at 20° off-axis, its focal length will be ~1 inch. The 2-mil spot has a diameter of 1/20 mm, so that to provide 80 elements/mm the optical system must demagnify 4:1.

Assuming the ability to look downward at 20° to the horizontal, at 1,000-ft elevation the forward view intercepts the ground 3,000 ft away, but at 5,000-ft elevation the intercept would be 15,000 ft away; the film transport can accommodate a film carrying an 8-by-8-inch image at most, or a ground coverage of 80,000 by 80,000 ft. Thus, the coverage to the horizon would be somewhat inadequate. Increased scanning power would have to be provided as well as a larger-diameter scanner tube.

If one scales the above constants by a factor of two, the film resolution goes up to 80 lines/mm, which might be done in monochrome if considerable care is taken, but cannot be approached at all in color. The camera lens would zoom from 0.5 inch to 2.5 inches, which is reasonable, but its resolution would not be likely to double to the 80 lines/mm that we would need. At a flight altitude of 5,000 ft with a 20° downward view, the visual ground intercept would be 15,000 ft away as before, and the total ground coverage on the 8-by-8-inch film would be 160,000 by 160,000 ft.

Alternatively, one may consider a design for the range 3,000 to 12,000 ft with 80 lines/mm resolution on the film and 15-ft ground resolution from 3,000 ft altitude. Thus 1 mm on the film is equivalent to 2400 ft on the ground, or 1 inch = 60,000 ft so that an 8-by-8-inch field covers an area of approximately 90 by 90 miles. This design is based on the assumption that it will be possible to achieve a total resolution of 4.10^8 picture elements on the 8-by-8-inch sheet of film; a fairly high degree of control will be needed, since it is generally agreed that 2×10^7 elements per field is the resolution level at which the film-lens resolution problem ceases to be routine. Horizontal sweep scanning power is the controlling factor in the design, which would have to be worked backwards to determine the optimum compromise.

V PERFORMANCE OF THE MECHANICAL X, Y, θ SYSTEMS

The X and Y servo systems are both dual-speed, with coarse and fine slew; however the coarse slew is used only for initializing the X,Y coordinates of the aircraft. When the X-velocity servo is driving the carriage at its limiting speed the carriage velocity is equivalent to a 2-inch motion in 17 seconds. Assuming a ground scale of 1 inch ≡ 5,000 ft, this corresponds to a ground velocity of

$$\frac{5,000}{17} \cdot 2 = 588 \text{ ft/s} \sim 350 \text{ knots} \quad .$$

Alternatively, at 1 inch ≡ 2,500 ft the limiting ground speed would be 175 knots. The 2-mil-spot-size limitation of the scanner cathode ray tube converts to 5-ft resolution of ground detail for 1 inch ≡ 2,500 ft scaling of the film.

In the Y-direction, at limiting velocity, it takes 35 seconds for the carriage to travel 2 inches so that the maximum Y velocity is half of the maximum X velocity. It is intended that the X-direction be aligned with the runway.

The response of the azimuth servo to an impulse of 21° from the control panel is shown in Fig. 2, which displays the tachometer output (i.e., angular velocity) on a scale of 0.5 s/cm. This shows maximum angular velocity after 0.2 seconds and a fully re-stabilized condition after 1.3 seconds. It is improbable that any aircraft has been designed to accept accelerations of this magnitude.

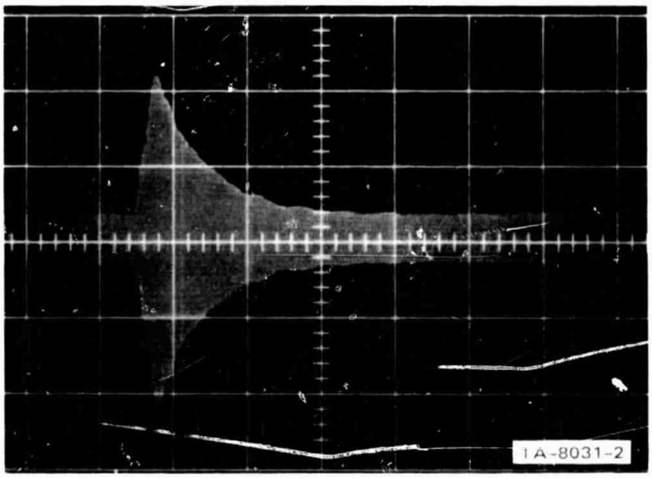

FIGURE 2 OUTPUT FROM AZIMUTH TACHOMETER AFTER IMPULSE EQUIVALENT TO 21-DEGREE ROTATION
TIME AXIS 0.5 s/cm

VI RECOMMENDATIONS

The factor limiting the resolution of the equipment as it presently exists is horizontal sweep scanning power. It is recommended that the scanner cathode-ray tube be replaced by one of greater diameter (say, 9 inches or larger), with smaller spot size and therefore demanding greater voltage on the final accelerator anode (e.g., 35 kV as against 25 kV). In order to sweep the spot from the stiffer beam across a wider tube, greater scanning power will be required (three times as much current in the coils represents nine times the power). The optical system would need to be replaced by one giving 2:1 reduction in the spot size on the film as compared with the spot on the tube face. If these changes are made there will be a substantial improvement in resolution; presently the lack of resolution on landing approach is very apparent, since the horizontal resolution becomes roughly equivalent to a 100-line television image.

A method has been examined for the modification of the system for the range 1,000 to 4,000 ft and from 3,000 to 12,000 ft using a zoom lens to provide the variable magnification of ground detail corresponding to changes in height. Since the aircraft will normally be flying level, rather than in a nose-down attitude for landing, there will be difficulty in extending the image to the horizon. Here too, greater scanning power and a larger scanner-tube diameter would seem to be essential if an acceptable level of ground resolution is to be reached, although it might be thought advantageous to trade ground resolution for better coverage toward the horizon.