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**A METHOD FOR MEASURING AIRCRAFT HEIGHT AND
VELOCITY USING DUAL TELEVISION CAMERAS**

By W. Robert Young

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A METHOD FOR MEASURING AIRCRAFT
HEIGHT AND VELOCITY USING DUAL TELEVISION CAMERAS

By W. Robert Young

SUMMARY

A unique electronic-optical technique, consisting of two closed-circuit television cameras and timing electronics, was devised to measure an aircraft's horizontal velocity and height above ground without the need for airborne cooperative devices. This system is intended to be used where the aircraft has a predictable flight path and a height of less than 660 meters (2,000 feet) at or near the end of an air terminal runway, but is suitable for greater aircraft altitudes whenever the aircraft remains visible.

Two television cameras, pointed at zenith, are placed in line with the expected path of travel of the aircraft. Velocity is determined by measuring the time it takes the aircraft to travel the measured distance between cameras. Height is determined by correlating this speed with the time required to cross the field of view of either camera. Preliminary tests with a breadboard version of the system and a small model aircraft indicate the technique is feasible.

This system is simple, cost effective, and fulfills the initial requirements of the Aircraft Height and Airspeed Indicator Program (AHAI).

INTRODUCTION

A method for determining the height and ground speed of aircraft is required in support of aircraft noise signature measurements. The distance from the noise source (aircraft) to ground-based microphones must be determined

so that the sound pressure measurements can be corrected for propagation losses. Typically, an array of microphones is placed along and on both sides of the aircraft's expected path of travel as projected on the ground. Once the aircraft's height and velocity at some known point relative to this array is determined, the distance from each microphone to the aircraft can be calculated for each data point.

The system described here is capable of determining the height and ground speed of an aircraft. Two ground-based, closed-circuit television cameras are placed along the aircraft's expected path of travel. Velocity is determined by measuring the time it takes the aircraft to travel the measured distance between cameras. Height is determined by correlating this speed with the time required to cross the field of view of either camera. Measurements of aircraft flying as high as 660 meters (2,000 feet) can be made with sufficient accuracy (5 percent or better) to satisfy the requirements for aircraft noise signature measurements. Measurements can be made on aircraft at greater altitudes with a proportional increase in error if the aircraft can be resolved by the television cameras. Height and ground speed measurements can be made on any aircraft without using airborne cooperative devices such as transponders, beacons, or reflectors. This system is low in cost, portable, simple in operation, and does not require a moving or tracking mount.

Another approach to measure aircraft height and ground speed is to use an aircraft radar altimeter on the ground in an upside down configuration. It has been determined that radar altimeters are not as accurate in this application as the dual television camera method due to excessive acquisition time and inability to determine zenith crossing times with sufficient accuracy.

The higher sampling rate of the television approach also enables this system to measure higher aircraft speed at lower altitudes.

This system is being developed in support of the Langley Research Center's Aircraft Height and Airspeed Indicator Program (AHAI).

SYSTEM DESCRIPTION

Two television cameras separated by a measured distance and pointed at zenith are placed in line with the expected path of travel of the aircraft. Velocity is determined by measuring the time the aircraft is traveling the measured distance, using zenith crossings as the reference points from which time is measured. Height is determined by correlating this speed with the time required to cross the field of view of either camera.

System Geometry

Figure 1 illustrates the geometry of the proposed method. The parameters are defined as listed below:

S = average aircraft ground speed between cameras

H = average aircraft height above television cameras

ϕ = television camera lens angular field of view

d = distance across field of view at height H

D = distance between television cameras

t_1 = time required for the aircraft to travel distance d

t_2 = time required for the aircraft to travel distance D

S is determined from t_2 using the relationship

$$S = \frac{D}{t_2} \quad (1)$$

From the geometry of figure 1, we can write

$$\frac{d}{H} = 2 \tan \left(\frac{\phi}{2} \right) \quad (2)$$

$$d = t_1 S \quad (3)$$

Hence,

$$\frac{t_1 S}{H} = 2 \tan \left(\frac{\phi}{2} \right) \quad (4)$$

$$H = \frac{t_1 S}{2 \tan \left(\frac{\phi}{2} \right)} \quad (5)$$

Equations (1) and (5) above give the aircraft height and ground speed in terms which can be measured from the ground. Time measurements t_1 and t_2 are determined from the two television camera video signals by the timing electronics.

Television Principles

A brief review of television scanning principles is necessary to understand the timing and detection technique used as well as the accuracy and resolution limitations.

In a standard television system, there are 525 scan lines per frame with two interlaced fields per frame, each field having 262.5 lines. The television picture is scanned from left to right at a uniform rate along lines that are evenly spaced as shown by the solid lines in figure 2. When the end of a line (such as line 'ab') is reached, the scanning spot returns or returns to the left (such as from point b to point c) and a new line is started (such as 'cd'). Simultaneously with the left to right movement, the spot moves downward at a constant rate causing each line to start at a point slightly below the end of the previous line. When the bottom of the picture is reached,

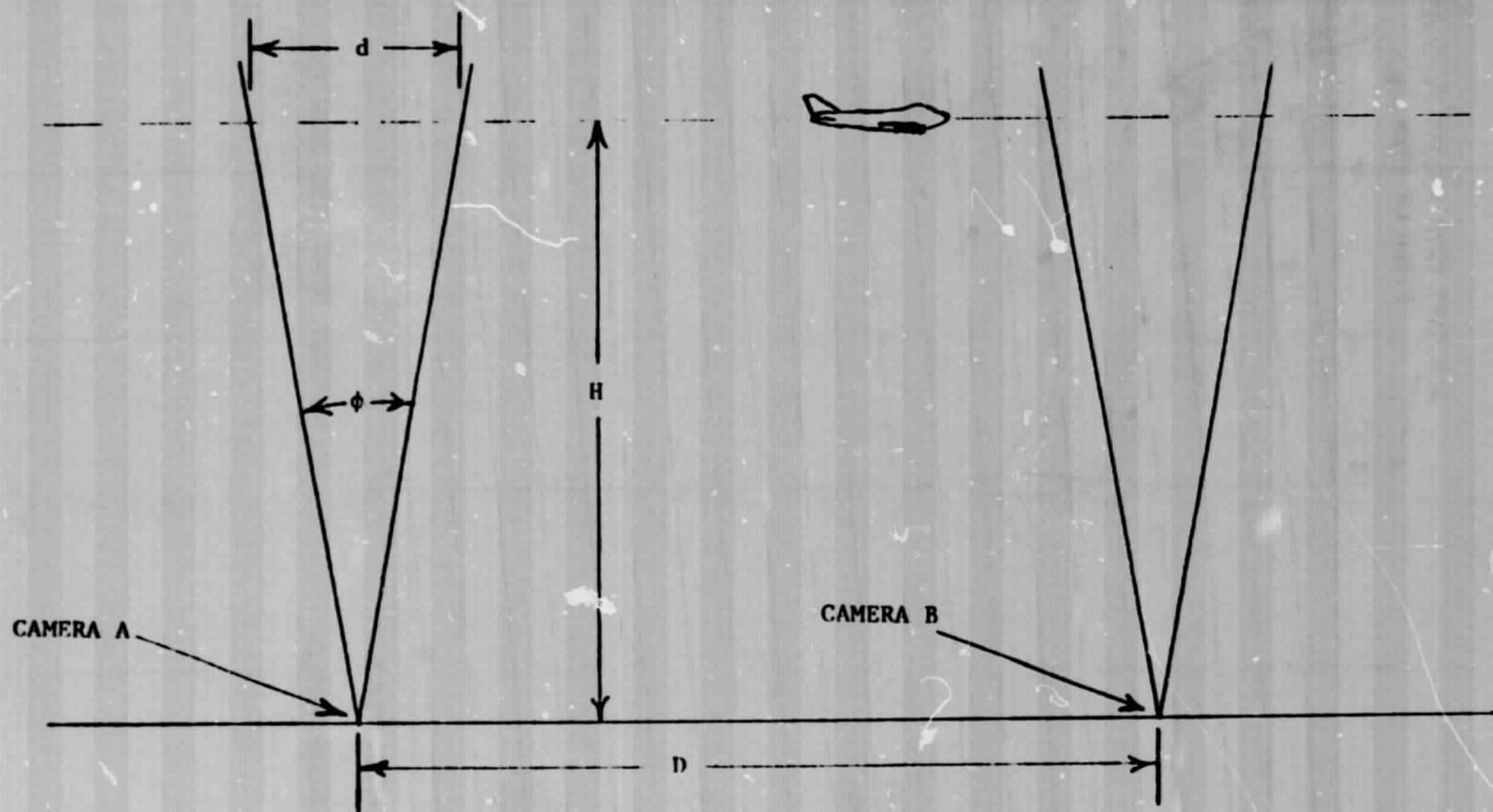


Figure 1. - System geometry.

Birds are distinguished from aircraft by using the fact that they are not as likely to fly over both cameras as are the intended aircraft. There will be infrequent occasions when either a bird or a cloud will give false triggers. Fortunately, both situations are temporary.

Timing Electronics

When both cameras are positioned to measure t_1 and t_2 , their scan lines are perpendicular to the aircraft flight path as shown in figure 2, and scan line 122 of both cameras is pointed at zenith (scan line 122 is approximately the center scan line). The timing electronics determine t_1 and t_2 by measuring the time intervals between the aircraft's image crossing selected scan lines. The third scan line from the top and bottom of each field (lines 3 and 241) is used for determining field of view passage time t_1 . The center scan line, number 122, is used to mark the aircraft's zenith passage for both cameras. From these zenith passage times, t_2 is determined.

Figure 3 shows a block diagram of the timing electronics. The horizontal and vertical oscillators in camera B are synchronized with those of camera A. The horizontal and vertical synchronization pulses are fed to the line counter decoder. The horizontal pulses increment the counter while the vertical pulses reset the counter at the beginning of each field. Hence, the count registered by the line counter corresponds to the line number being scanned by both cameras. The line counter is decoded to give an output pulse while lines 3, 122, and 241 are being scanned. These output pulses are used by the video gating and counter control circuit to start and stop counter T_1 when lines 3 and 241 of camera A show an aircraft crossing and start and

stop counter T_2 when line 122 of cameras A and B are crossed by an aircraft. The counts displayed by T_1 and T_2 correspond to times t_1 and t_2 , respectively.

Test Results

Numerous tests have been conducted which were necessary for design purposes but which also demonstrate that this technique is feasible. Initial tests used a small model aircraft suspended on a fine wire above a television camera pointed at zenith. A high degree of contrast was realized in the video signal between the model aircraft and the sky background. Under these near ideal conditions, the differentiator easily picked out the model aircraft against the sky background.

It was thought that more difficulty would be experienced in distinguishing real aircraft against different sky backgrounds. Television video recordings were made of numerous aircraft against different types of sky backgrounds (clear, cloudy, partly cloudy, etc.) and for different sun angles. As suspected, the contrast between the sky and aircraft was not as great in many of these situations. These recordings were played back through the differentiator circuit to aid in its final design and to find the best compromise adjustments of the differentiator time constants and gain for the different light and cloud conditions.

The timing electronics were tested and debugged in conjunction with the differentiator in many of the above tests. It functioned as designed when supplied with the proper signals from the differentiator.

ERROR ANALYSIS

This error analysis assumes that the aircraft will fly a straight and level course and maintain a constant ground speed while passing over the microphone and television camera array.

Several other factors were found to contribute to the overall system error. Those considered most significant are sampling rate, scan line shift, and camera position.

Sampling Rate Error

Each of the gated scan lines (lines 3, 122, 241) are sampled once per field. It follows that the one-sixtieth of a second required to scan a field corresponds to a sampling rate. Since the two television cameras are synchronized, both t_1 and t_2 are subject to be in error by as much as one-sixtieth of a second. Figure 4 gives this error as a percentage part of t_1 for different aircraft heights and velocities based on a television camera lens field of view, ϕ , of 20° .

Figure 5 gives the corresponding percent error for t_2 as a function of aircraft velocity and television camera spacing.

It should be emphasized that figures 4 and 5 give worst-case sampling rate error. This error could have any value from zero to the value shown for a particular set of conditions.

Scan Line Shift Error

This error results from one or more of the selected scan lines (lines 3, 122, 241) changing their relative position on the television camera image tube. These shifts might be caused by temperature variations, circuit

voltage variations, changes in component values, and television camera adjustments.

A TeleMation Model 1100 television camera, which is the type planned for use in this system, was evaluated as to its scan line drift. When this camera was subjected to a 20°C (35°F) change in temperature, the center scan line was observed to change position by two scan lines. When operated at a constant ambient temperature, one scan line shift was observed over a 4-hour time period.

The effect of scan line shift on t_1 is a direct ratio of the number of lines shifted to the number of lines between line 3 and line 241. Hence, percent error of t_1 is given by

$$\text{Error} = \frac{N}{238} \quad (6)$$

where N = number of scan lines shifted. The effects of scan line shift related to the corresponding percent error in t_2 is a function of H , D , ϕ , and N . Figure 6 shows this relationship for $N = 1$ and $\phi = 20^\circ$.

Camera Positioning Error

The accuracy with which distance, D , is measured, and the error in pointing the television cameras to zenith are additional error considerations. For $\phi = 20^\circ$, the zenith-pointing angle error should be 0.1° or less. This is an angle error of one in 200 or approximately the same as one scan line error. The accuracy with which D can be measured using a steel tape far exceeds that required by the system.

Miscellaneous Errors

Numerous other sources of errors such as cable delays, oscillator frequency shift, the slight skew of television scan lines to the path of the aircraft, etc., have been examined and found to be insignificant. Another minor source of error is television camera image lag. This occurs when an aircraft crosses the field of view at a high rate of speed and results from the delay in response of the photo material used in the camera image tube. This characteristic should cause an equal delay in detection of aircraft scan line crossing, and consequently, tend to cancel itself.

CONCLUSIONS

Based on the above error analysis, the overall system should be capable of measuring aircraft speed and height with an rms error of between 1 percent and 4 percent -- depending on conditions.

Numerous tests have been conducted which prove the feasibility of this technique. This system is simple, cost effective, and will fulfill the requirements of the AHAI program. Its advantage over the radar altimeter approach is that it provides precise zenith crossing time for each camera and has a higher sampling rate. The higher sampling rate enables this system to measure higher aircraft speed at lower altitudes.

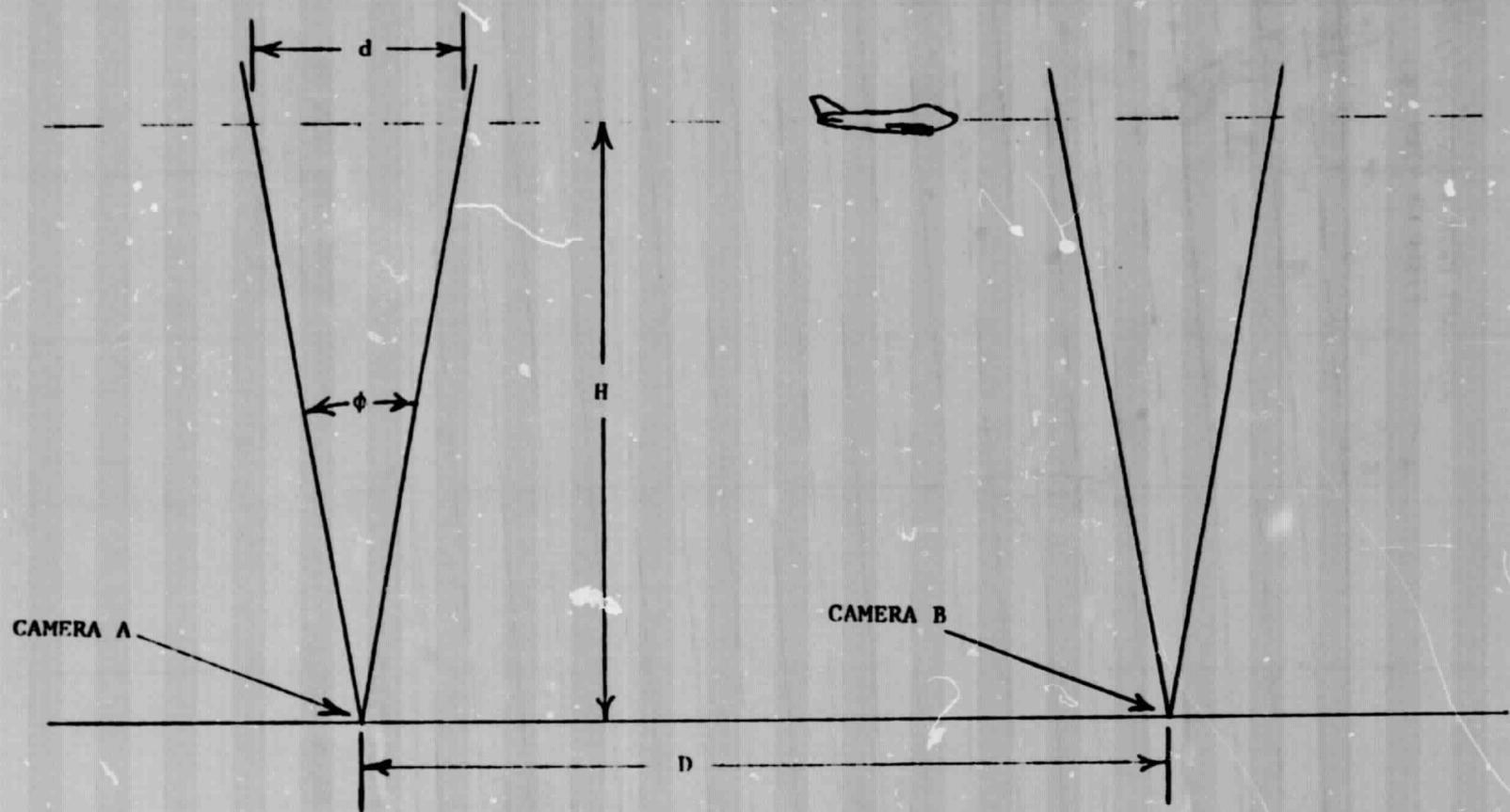


Figure 1. - System geometry.

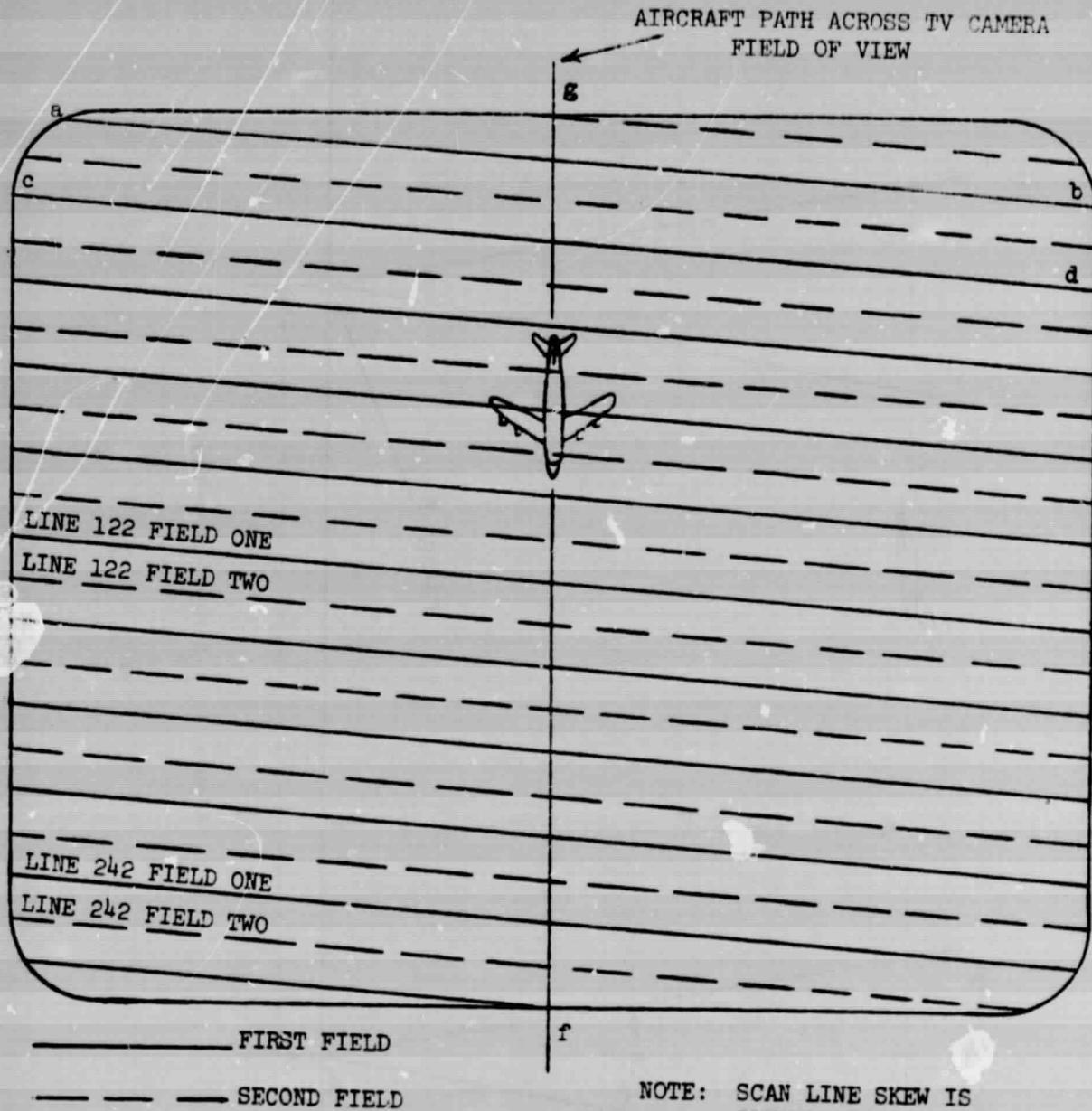


Figure 2. - TV scan line format.

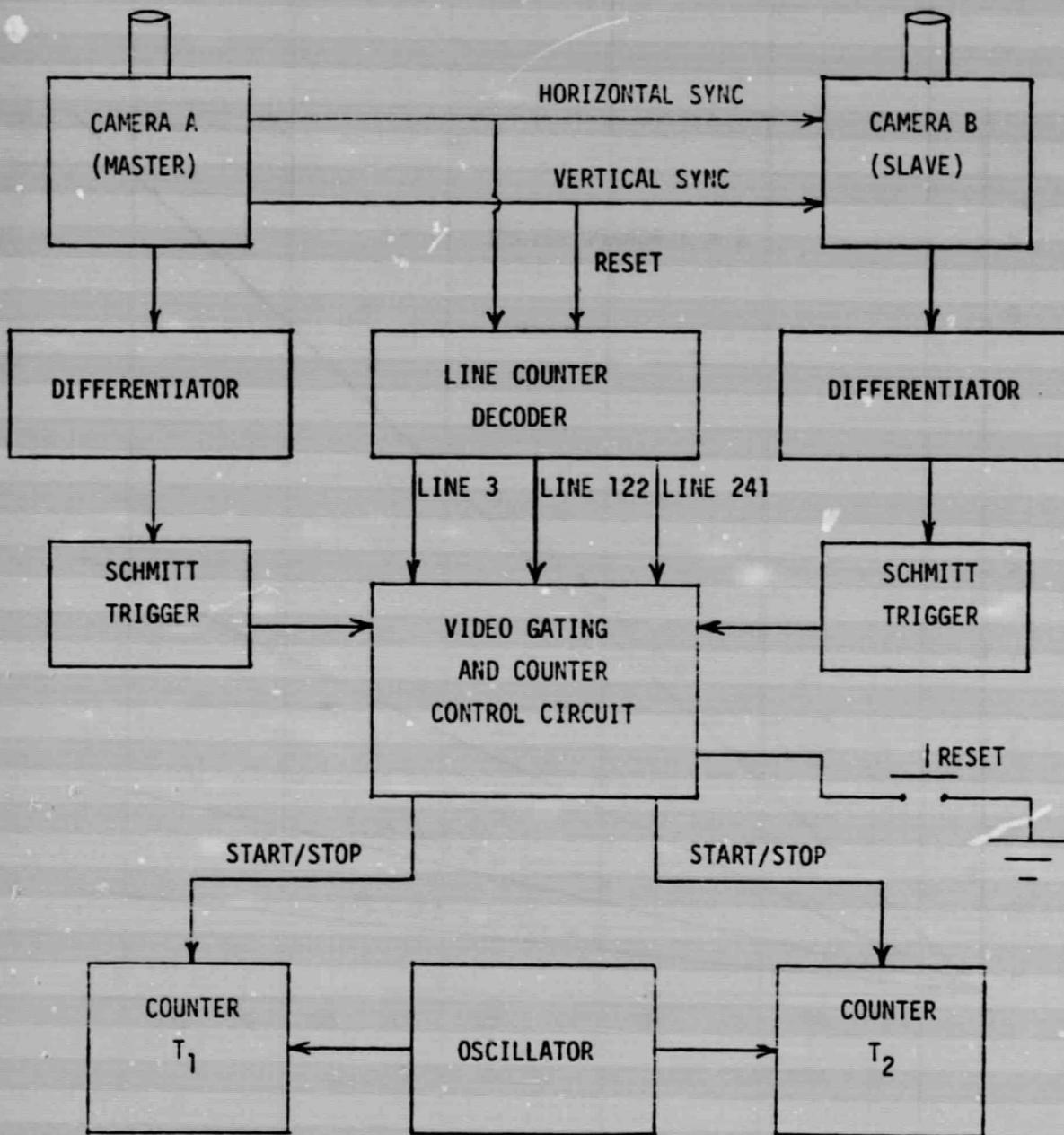


Figure 3. - Timing electronics.

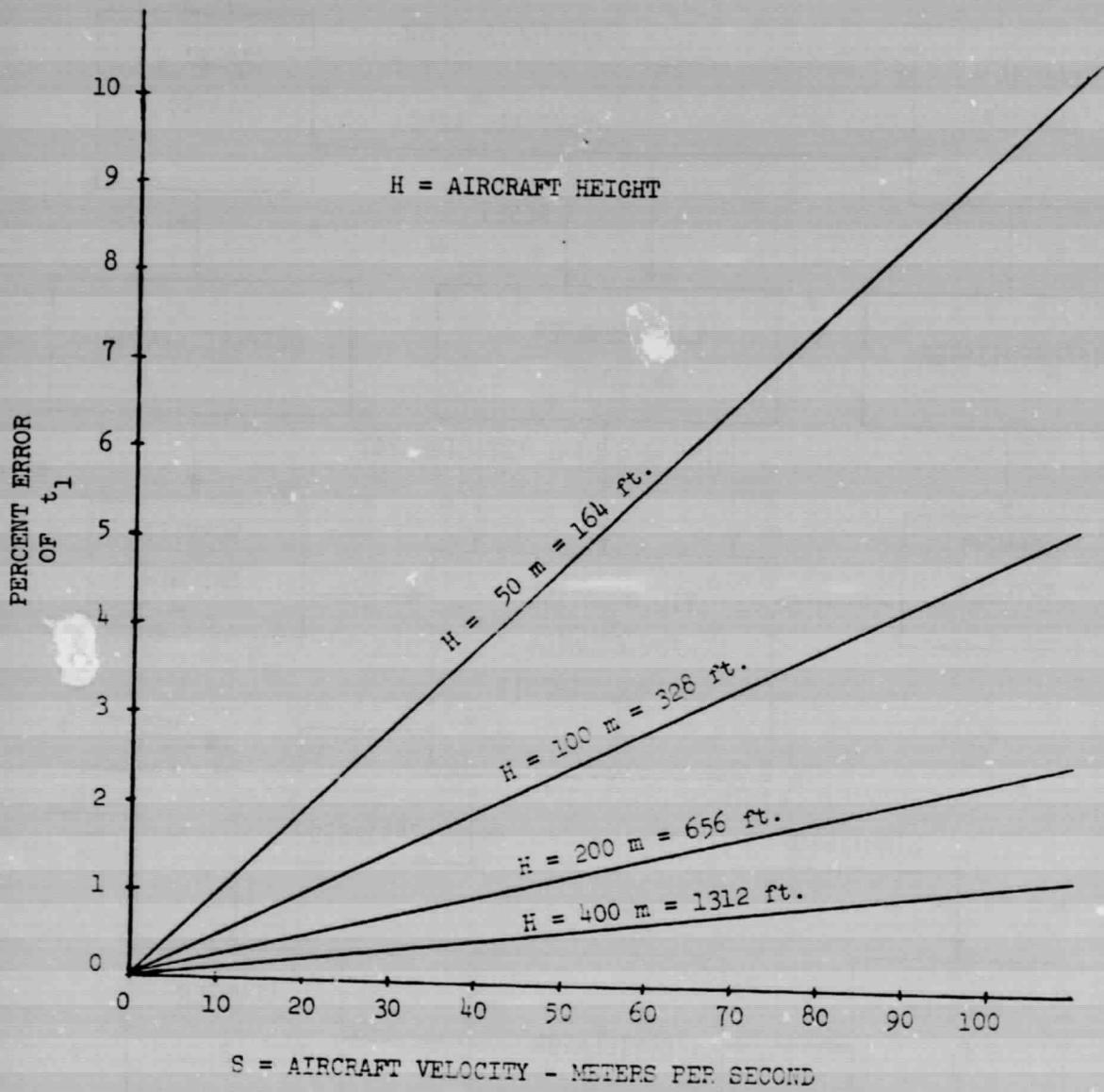


Figure 4. - Sampling rate error (t_1).

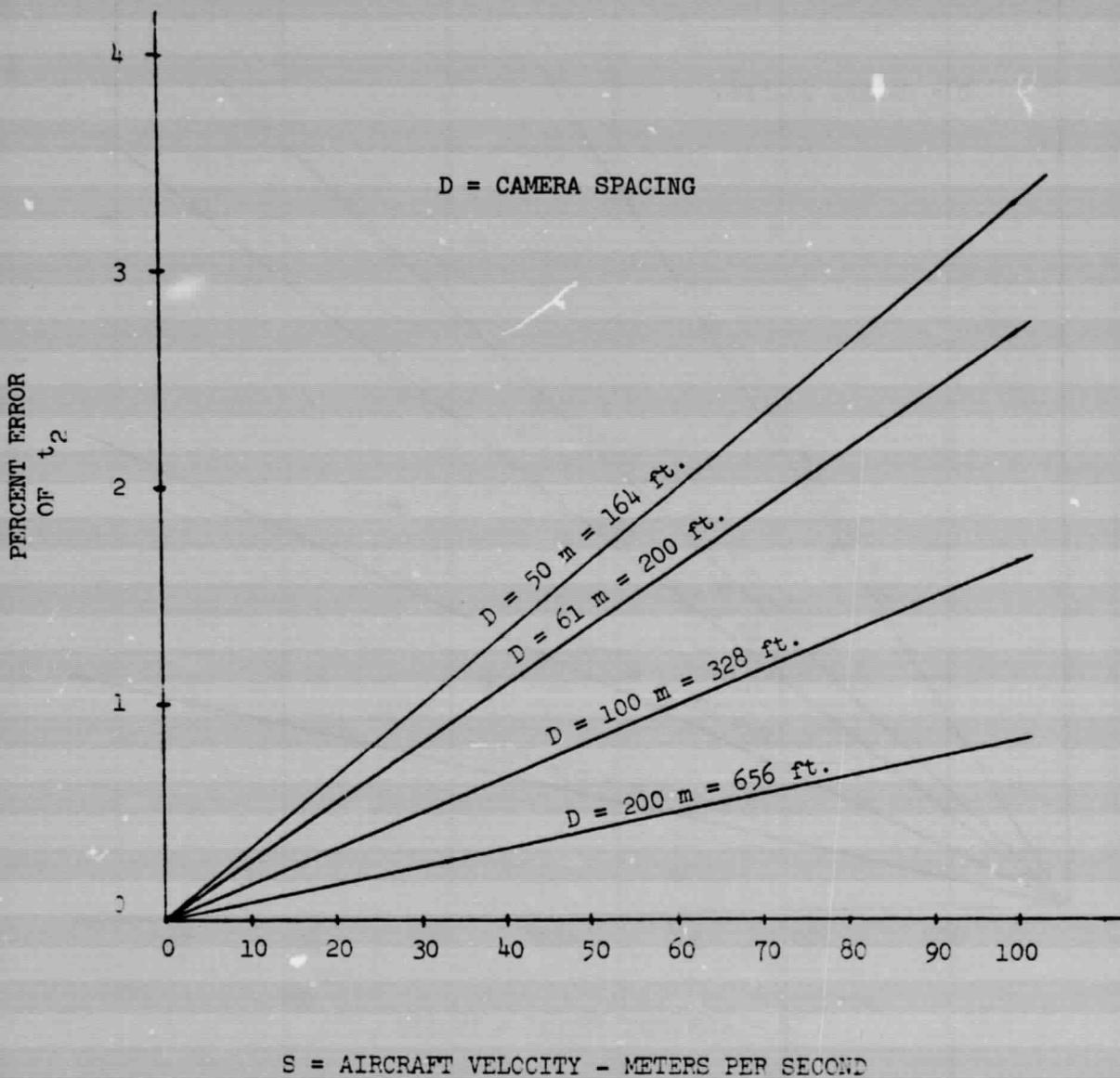


Figure 5. - Sampling rate error (t_2).

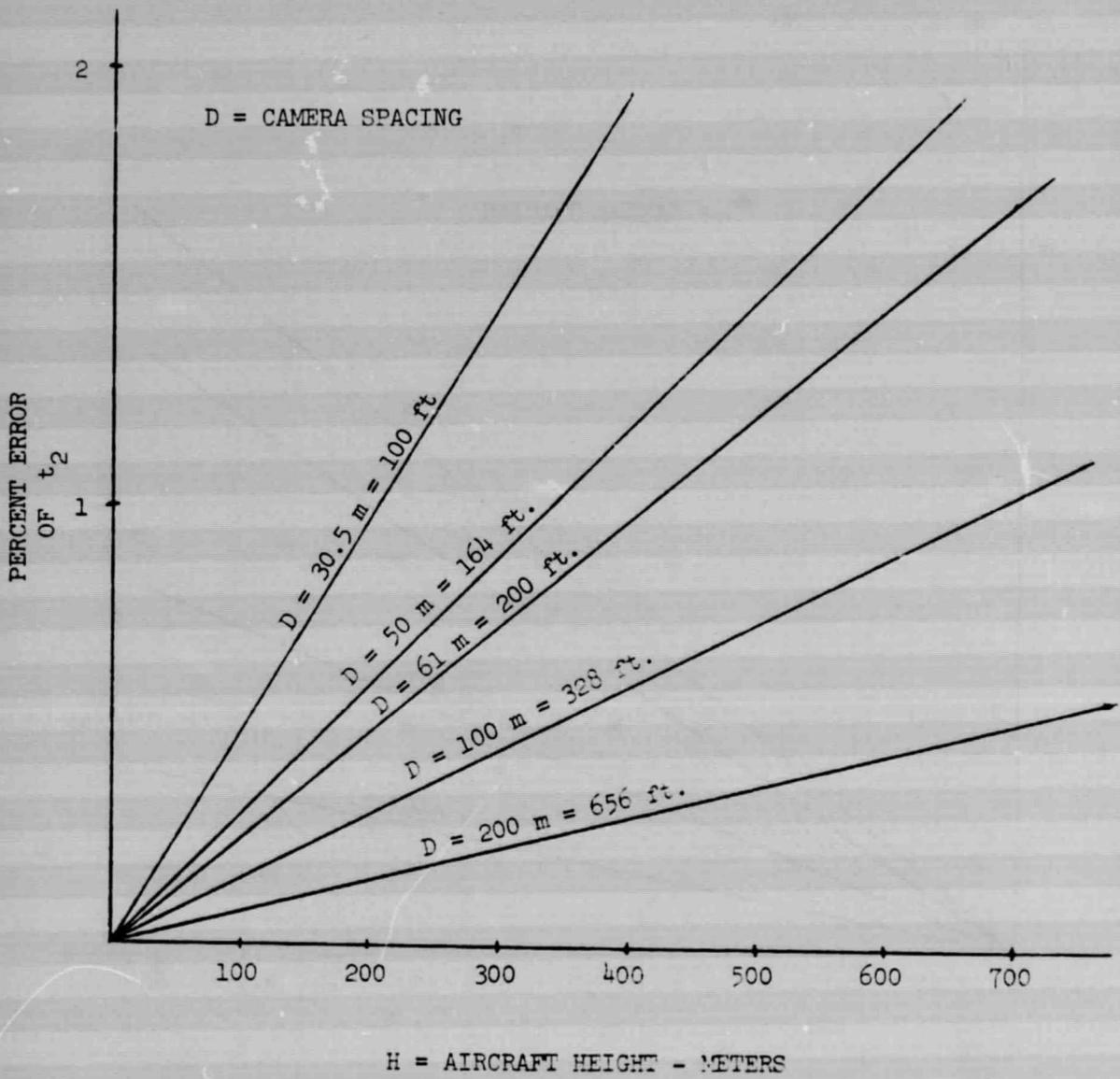


Figure 6. - Error in t_2 for one scan line shift.