COMPARISON OF TWO TECHNIQUES OF AERIAL
PHOTOGRAPHY FOR APPLICATION   IN
FREEWAY TRAFFIC OPERATIONS STUDIES

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INTRODUCTION

It is becoming more apparent each year that many sections of urban freeways will have to be controlled during peak hour traffic. The need for knowledge on how, when, and where to control the traffic has resulted in the development and installation of several types of surveillance systems to monitor freeway operations. Electronic sensing and automatic control devices provide the best solution, but equipment that is now available cannot accurately describe traffic operation over long sections of freeways. It is doubtful that these systems will be developed until a more complete criterion for the operation of a freeway system has been established. Television monitoring systems, now in operation in several locations, are providing much of the needed data, but not all study sections can, nor should be equipped with complete television coverage. It is for that reason that aerial surveys, which approximate the coverage provided by continuous television monitoring, were used to study the traffic flow on the Gulf Freeway in Houston.

The application of aerial photography to traffic studies is not a recent innovation. Reports of the use of aerial photography were available as early as 1927.*[1] However, there has been no serious consideration of this study method because of two factors: (1) the cost of the field study, and (2) the difficult and time consuming task of data reduction.

The same objections were raised when proposals to study freeway operation by motion picture film from ground locations were being considered. But the results of these film studies have provided a better understanding of the traffic flow characteristics, improved designs of entrance and exit ramps on the freeways and improved signalization of the intersections within the interchanges.

However, these motion film studies from ground locations have limitations that must be considered. Numerous studies of freeway operation have documented the fact that a small disturbance at one location on the freeway, during peak volume conditions, can create complete stoppages at some distance upstream. Therefore, a study that is limited to a small section will reflect the change in operation without recording a cause to relate to it. The use of aerial photography permits the expansion of the study area, not only along the freeway, but also laterally to cover the frontage road and supporting street system.

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*1 - Number refers to references listed at the end of the report.

Objectives of the Study

Aerial surveys were made of the traffic flow on a six-mile section of the Gulf Freeway in Houston, Figure 1. Two types of aerial photography were investigated: (1) strip photography where two continuous pictures are taken simultaneously from the beginning to the end of the study section: and (2) time-lapse photography where individual pictures are taken at short intervals of time, Figures 2 and 3.

The objectives of this study were:

(1) To determine the operational characteristics of the freeway and those factors that affect the level of service offered to the motorist.

(2) To evaluate the two techniques of aerial photography and their application to traffic studies.

The results of the study of operational characteristics will be reported in another paper. The purpose of this report is to compare the two types of aerial photography used in this study for their application to traffic studies. It is very difficult to evaluate the performance or applicability of these two aerial photographic techniques from this limited study, because many of the disadvantages experienced in this study can be eliminated with more detailed planning and advance preparation of the test area based on the experience gained in this work. This paper reports the results of the study as performed and the changes that need to be made in future studies.

Previous Work

Only in the last two years have any extensive studies of traffic operations by aerial photography been undertaken, although many experiments have been reported.[2,3,4] Wohl[5] presented the application of the strip photography for traffic studies and the relationships of speed, volume and density as measured from the film. The fundamental principles for the continuous strip stereo photography are covered extensively in Wohl's paper and, with the exception of Figures 6, 7, and 8, are not included in this report.

Wagner and May[6] reported the results of a density study of freeways in California using time-lapse photography. A significant development in this paper is the method of presenting density condition of the freeway by a time-distance-density contour map.

CORRIDOR AREA

ROUTE MAP
OF
HOUSTON
Scale of Miles

SURFACE STREET
DISTRIBUTION SYSTEM

DOWLING

C.B.D.

I. & G.N. RR

SCOTT ST.

CULLEN

H.B. & T.RR

H.B. & T. RR

TELEPHONE

WAYSIDE

GRIGGS

225

PARK PLACE

I.H. 35

TO NASA

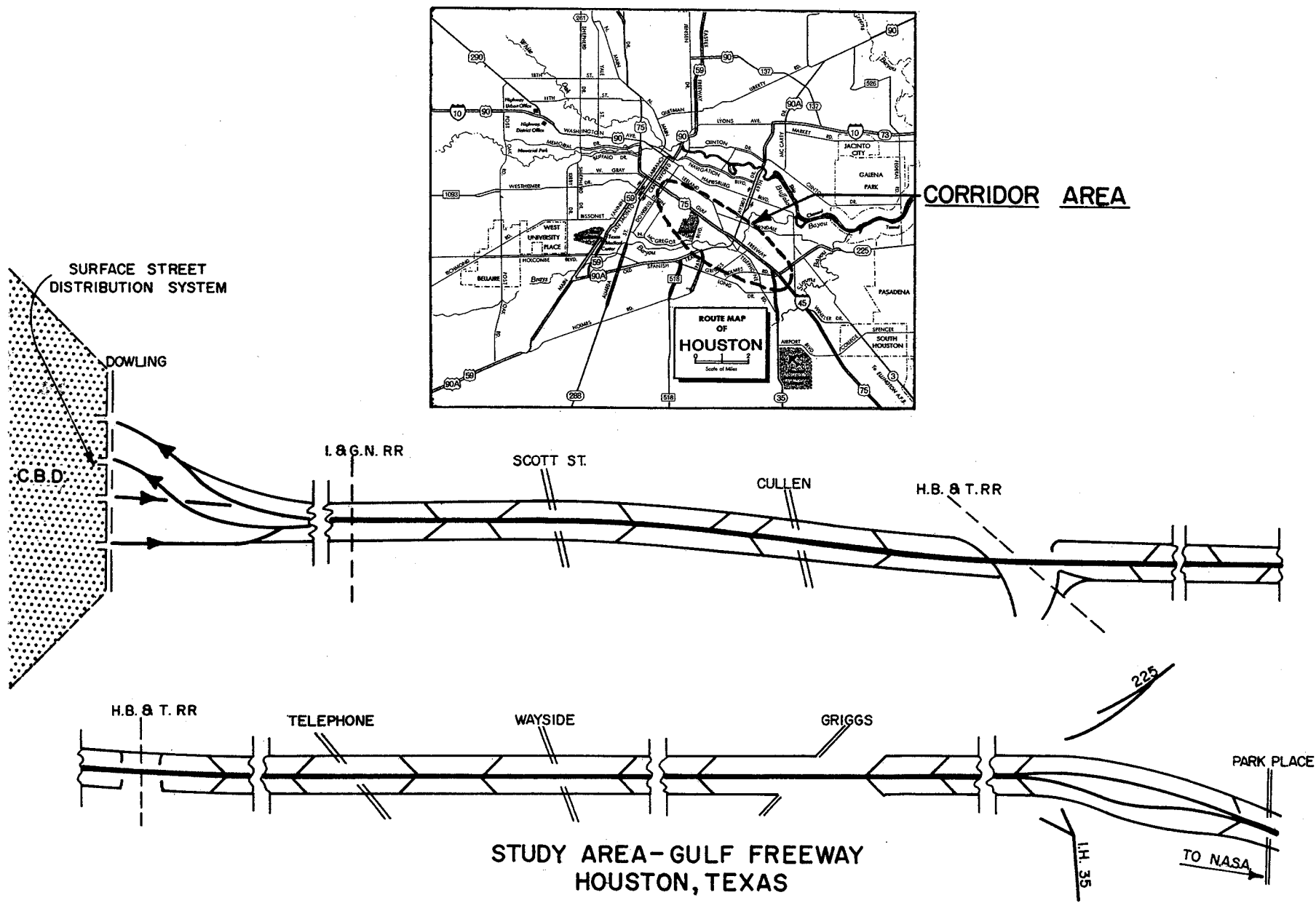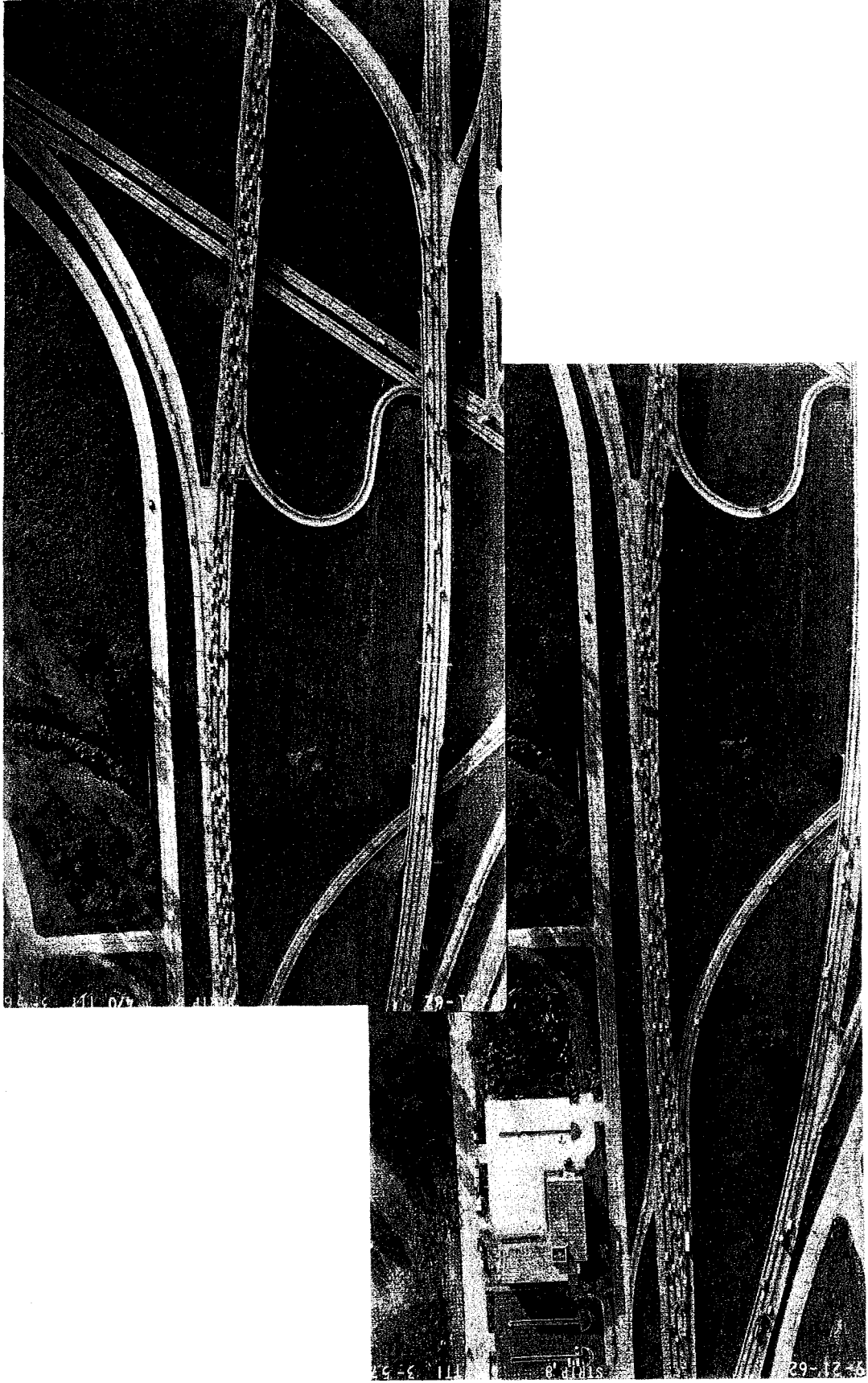STUDY AREA-GULF FREEWAY
HOUSTON, TEXAS

FIGURE I

CONTINUOUS STRIP STERESCOPIC PHOTOGRAPHY

FIGURE 2

TIME LAPSE PHOTOGRAPHY

FIGURE 3

Howes[7] reported an extensive study in the application or aerial photography to the collection and analysis of highway traffic flow data. Results of time-lapse photographic studies were compared to those obtained by conventional ground techniques. Analyses of the cost and procedure of data reduction and the accuracies of the results were made and included continuous strip aerial photography, although no surveys were made using this technique.

There have been other reports on the application of aerial photography to traffic operations[8] and freeway design[9] but these studies are primarily concerned with some form of road or equipment inventory.

STUDY PROCEDURE

Description of Field Study

The section of the Gulf Freeway in the study area extends from the Reveille Interchange at the intersection of Highways U.S. 75, State 225, and State 35, to the downtown distribution system at Dowling Street, Figure 1. The flights were made in the morning peak period from 6:30 a.m. to 8:00 a.m. for two weekdays in September.

Two planes were used to make the film study; one equipped with a 24-inch focal length camera for filming time-lapse photographs and the other equipped with a 4-inch focal length camera for filming the continuous strip photographs, Figures 4 and 5. Both planes were fixed wing Cessna 195's.

The flight plans required the two planes to be separated by at least a two-minute interval. The continuous strip photographs were filmed from an altitude of 1,000 feet and the time-lapse photographs were filmed from an altitude of 2,500 feet. Only one filming run each day was made in the outbound direction against the peak traffic flow. All other filming runs were made in the direction of peak traffic flow. This is an important consideration in the design of the study for the following reasons:

(1) Time-lapse photographs will have a larger number of different vehicles, but with fewer readings per vehicle for the filming run against the flow of traffic.

(2) Strip films will have a larger number of different vehicles and the correction for density will be negative, that is, true density is less than that pictured on the film. This is caused by the time lag which is the length of time required to complete one film strip. Also, the size of the image of the vehicle will be shortened. This is especially important in attempting to identify the vehicles by type or by markings.

During the filming runs by the aircraft, traffic volume counts were made by ground observers at several locations on the freeway lanes and ramps. Control vehicles with distinguishing markings on the roofs made travel time runs. Two of these vehicles were equipped with speed recording equipment for tracing speed profiles.

There was no ground to air communication during the study. A time reference was established by synchronizing watches one-half hour before the start of the study.
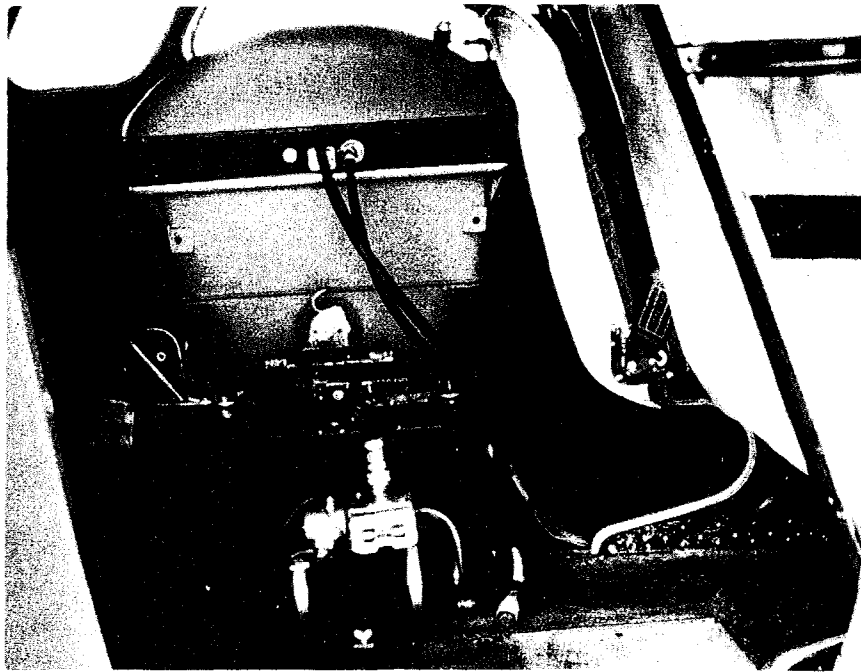
TIME LAPSE CAMERA
FIGURE 4
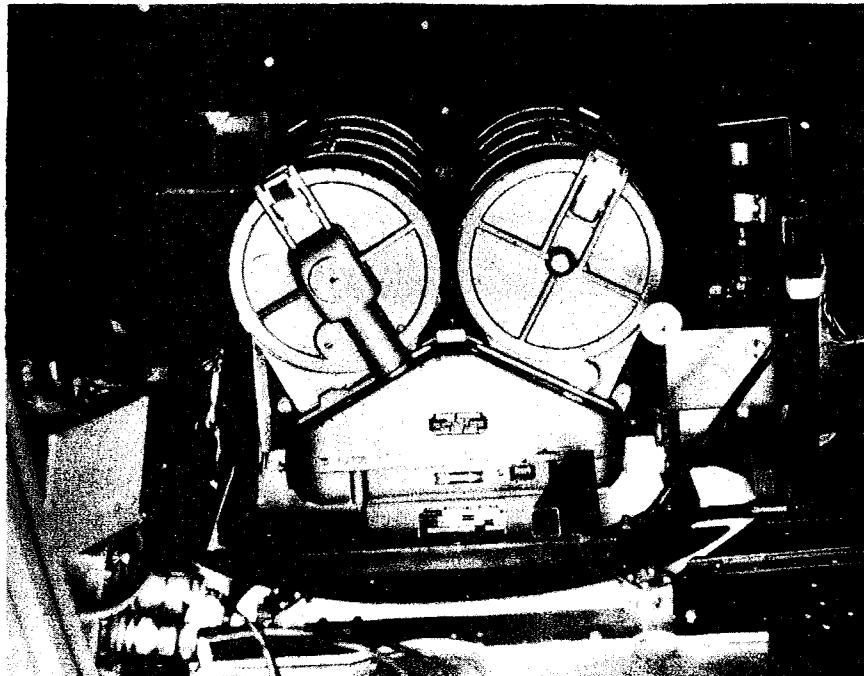
CONTINUOUS STRIP FILM CAMERA
FIGURE 5

Analysis of Film

The purpose of this study was to determine if aerial photography is practical for freeway operation studies. In the design of the data reduction procedure all information that could be of any value in traffic studies was read from the film. A time reference and the location of each vehicle by station number was recorded each time a vehicle was photographed. The location by lane, direction of travel and type of vehicle were also recorded at this time. Computer programs were developed to take these basic data and compute all desired traffic flow characteristics; such as speed, volume, density, headways, etc. The methods used in reducing the data from the film and the accuracy of measurements are discussed in other sections of this report.

The important feature of the data reduction procedure was the determination of the location of each vehicle by roadway station numbers. These numbers were very difficult and costly to obtain, but more detailed analyses by electronic computers were then possible for specified sections of roadway, certain numbered groups of vehicles, or for each individual vehicle.

Improvement of Study Procedure

Many problems that were encountered in this first study can be eliminated in subsequent projects. However, one difficulty over which there was no control was the weather. Low altitude flights over populated areas near the Houston International Airport required a minimum visibility of 5 miles that was difficult to obtain because of smoke and haze. The flights were delayed 3 to 4 days.

Communication between ground and air units is advisable. In some locations it is possible to use the control tower at a nearby airfield to provide the communication link between the plane and the study area.

Reference points on the ground should be established at short intervals. Beginning and ending markers, and two sets of intermediate reference points were used in this study, and station numbers were determined from plans of the freeway. Each film run had to be numbered separately. Transferring these station numbers to the photographs is a time consuming task, subject to errors that can be eliminated by placing these stations on the pavement before the study is made.

The reduction of data from the films is still a time consuming task, but one that can be alleviated by providing photographs of scales not smaller than 1 inch to 200 feet, magnifying lenses for reading measurements, and a recording procedure that relieves the reader at specified intervals.

The problem of film data reduction has been lessened by the use of computer programs and a reduction procedure that records at the same time all the basic information needed to make all the anticipated analyses.

ANALYSIS OF THE TWO AERIAL PHOTOGRAPHIC TECHNIQUES

One of the primary objectives of this study was to develop the best procedure for obtaining traffic data from the aerial photographs and film strips. It was further stipulated in the development of the study that all traffic data available from the film will be recorded.

The procedure adopted for this study required basic measurements to determine vehicle location. A computer program was written to calculate all traffic flow characteristics. It is only possible to compare the two photographic techniques in terms of these measurements and the resulting cost of reduction and accuracy of data. From this study for example, it was not possible to determine which method required fewer man hours to determine only vehicle speeds, or space headways, or some other flow characteristic. A study requiring that only one or two of these parameters be measured would probably use a different data reduction procedure.

This procedure, which records all data in a form for calculation and processing by electronic computers, permits faster and more complete analyses of the aerial photographs. This compensates to some degree for the slow process of making measurements from the film.

Method of Data Reduction

Description of Methods

To determine all flow characteristics that are available from aerial photography, there are only two parameters that must be measured; the location of each vehicle at some known time, t, and the location of each vehicle at some known time, $t + \Delta t$. This information determines the speed of the vehicles from which other flow characteristics, such as volume, density, headways, etc. can be calculated. To obtain a complete analysis of the data available from the aerial photographs, the additional information of lateral location of each vehicle, type of vehicle and time of day are recorded.

Strip Photography

There are two ways of determining vehicular speeds from the strip film: (1) the conventional method is to measure the distance between the two images of the vehicle and divide by the time lag between photographs, (2) the other method is to measure the elongation of the vehicle's image due to the exposure time. This is a function of the vehicle speed relative to the known airplane speed.

Both of these methods were investigated and the placement method was selected. The vehicle elongation procedure required an accurate measurement of the length of the vehicle's image. This required a determination of the scale of the film. Also, the true length of the vehicle must be known, but since the vehicle's image was blurred, and the film scale was large, it was difficult to determine the identification of the vehicle and its actual length.

The displacement method was selected for use in this project. Figures 6, 7 and 8 present the time, distance relationships of the strip film. The precision of the speed measurements was a direct function of the precision of the displacement measurements. Therefore, several techniques were investigated for making these measurements. Figure 7 (a) illustrates the calculation of speed using the measurement of the vehicle's image.
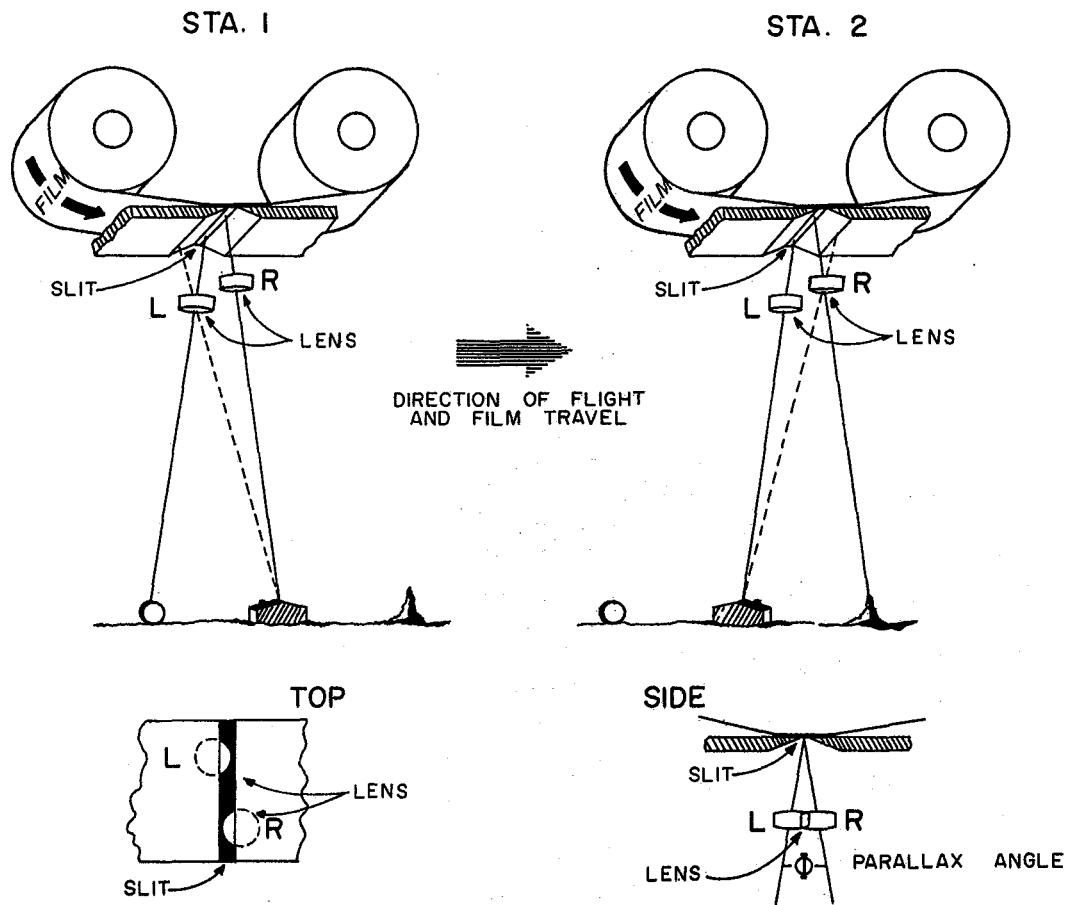
A stereo viewer, capable of reading displacements of 1/1000 of an inch was considered. This equipment, which relies on the depth perception of the reader, should be used by personnel that have received extensive training in its operation. This method was rejected because the precision of the measurements could not justify the cost of training the reader and renting the equipment.

The use of the stereo viewer on a contractual basis was also investigated, but the cost of data reduction was too high and the information received was not as complete as needed; that is, lane usage, location with respect to stationing, number of vehicles in the study area, were not included in the data reduction procedure.

The displacement method, used by our staff, requires the measurement of the vehicle displacement with an offset scale.

Because the scale was small, enlargements of one strip were made to determine what improvements in the accuracy of the reading could be expected. Since the film strip is a positive transparency, contact prints made directly from the film are reversed. This is not a serious problem, but it does induce some discomfort to the reader over long periods. The preparation of a negative from which to make the prints increases the cost of enlargement by twenty-five percent.

The maximum enlargement that can be processed by equipment available is three to one. The scale would be approximately one inch equals 100 feet. This method was rejected because the cost of enlargements could

STA. 1   STA. 2

SLIT

L   R   SLIT   L   R

LENS   LENS

DIRECTION OF FLIGHT
AND FILM TRAVEL

TOP   SIDE

L   SLIT

LENS   L   R

R   LENS   PARALLAX   ANGLE

SLIT

PLAN   AND   SIDE   VIEWS   OF   THE   CONTINUOUS
STRIP   FILM   CAMERA
FIGURE   6

H = Flight Height S_p = Plane Speed S_B = Speed of Moving Vehicle

A: (Fixed Object)

    t = Time that front lens "sees"
        Object A.
    t' = Time that rear lens "sees"
        Object A.
    D = Distance flown between t and t'

B: (Moving Obect)

    t_1 = Time front lens sees Bat
        position 1
    t_2 = Time rear lens sees Bat
        position 2
    D_p = Distance flown between t_1 and t_2

    D_B = Distance B has moved between t_1
        and t_2

TIME – DISTANCE RELATIONSHIPS
STRIP PHOTOGRAPHY
FIGURE 7

Road

Plan view

Lenth of
vehicle

$L + \Delta L$

Lenth of
filmed image

$$t_2 - t_1 = \frac{L + \Delta L}{S_P}$$

$$\Delta L = (t_2 - t_1)(S_B)$$

$$S_B = \frac{\Delta L}{L + \Delta L}(S_P)$$

S_P = Plane speed

S_B = Speed of moving vehicle

L = True lenth of vehicle

$L + \Delta L$ = Lenth of vehicle image
on continuous strip film
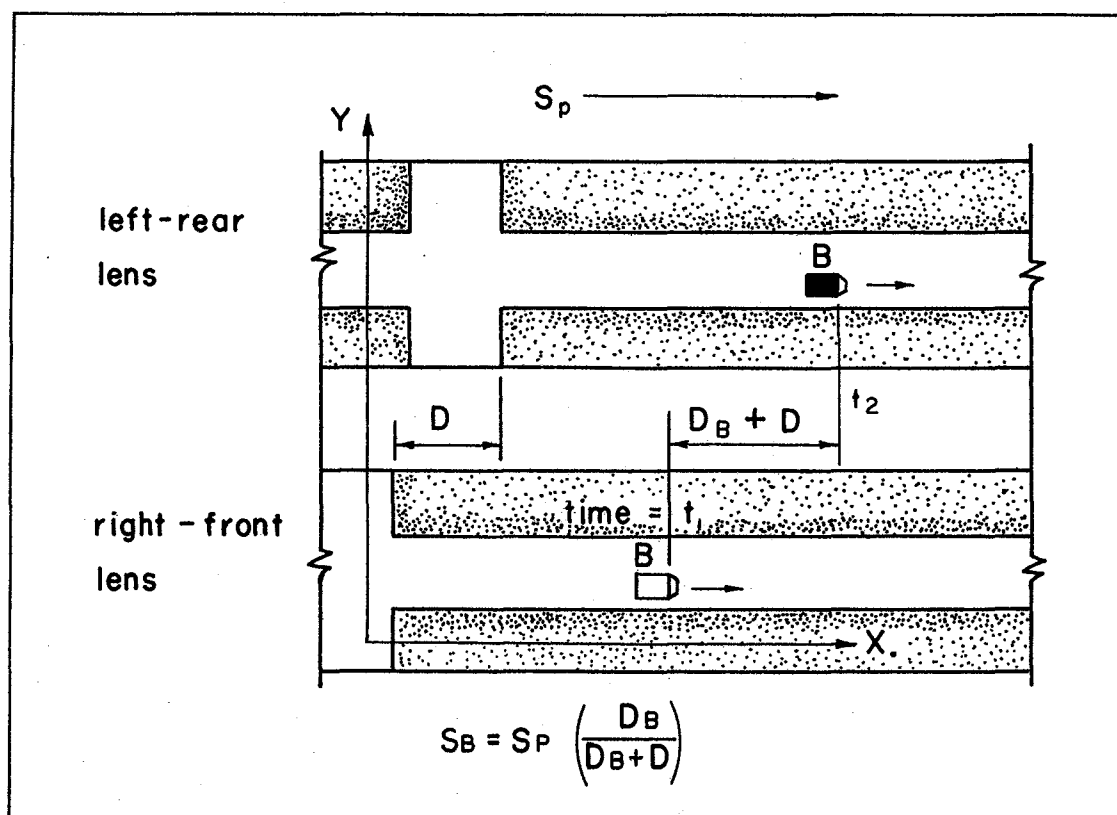
TIME – DISTANCE RELATION
OF STRIP PHOTOGRAPHY

FIGURE 7a

TIME – DISTANCE   RELATIONSHIPS
STRIP   PHOTOGRAPHY

FIGURE 8

not justify the increase in accuracy, and there was no significant reduction in the data reduction costs.

The technique selected was the measurement of data directly from the film transparencies. Figure 9 shows the light tables constructed for this study. A plexiglass reading frame was developed for making displacement readings. The off-set scale etched in the plexiglass was viewed through a magnifying glass. To make displacement readings a reference mark on the glass was positioned over a vehicle in the lower film strip. The frame was positioned perpendicular to the film border. The displacement was read at the location of the vehicle on the scale in the upper film strip. Measurements were read to the hundredth of an inch.

Time Lapse Photography

Vehicular speeds, headways and densities were calculated from the measurement of ground displacement of the vehicles from one photograph to another photograph, exposed at known time intervals, Figure 10. All other time dependent parameters were from these measurements. The time interval varied from run to run and had a range of 3 to 4 seconds. Variation of the time interval within the run was ± 0.1 seconds.

## Precision of Measurements

Continuous Strip Photography

The two readings made for each vehicle are represented in Figure 8: photo displacement, D, measured from the film in inches; vehicle plus photo displacement, $D_b + D$, as measured from the film in inches.

Speed is calculated from the equation:

Vehicle Speed = Plane Speed $\dfrac{(\text{Vehicle Displacement})}{(\text{Vehicle plus Photo Displacement})}$

The accuracy of the vehicular speeds and all flow characteristics dependent on speed is influenced by the precision of these measurements and by other factors listed below:

Variation in Observers - The equipment used in taking the measurements limited the displacement readings to the nearest one-hundredth of an inch. The readings depend somewhat on the recorder's judgement. Comparisons of the same set of readings made by two different recorders show the difference between observers to be negligible. The average difference and standard deviation were about the same as the two readings by the same observer.
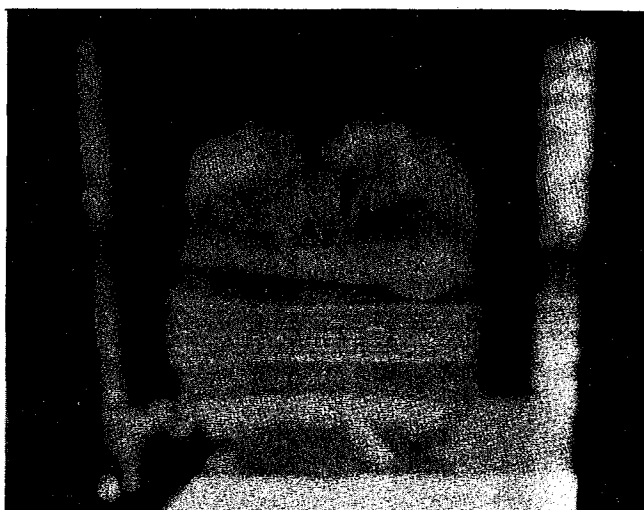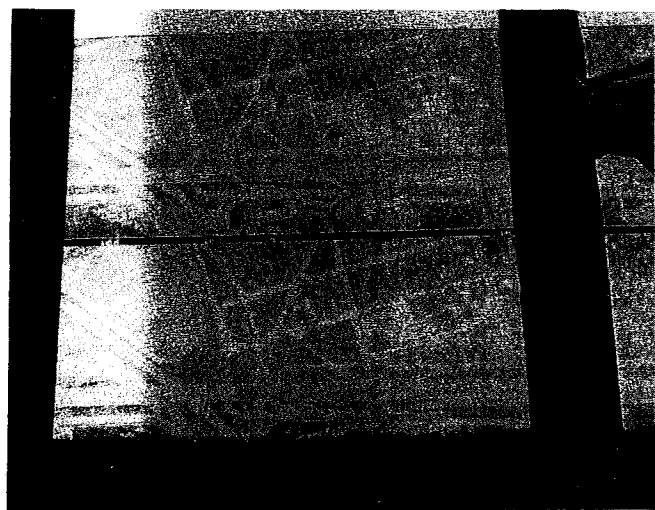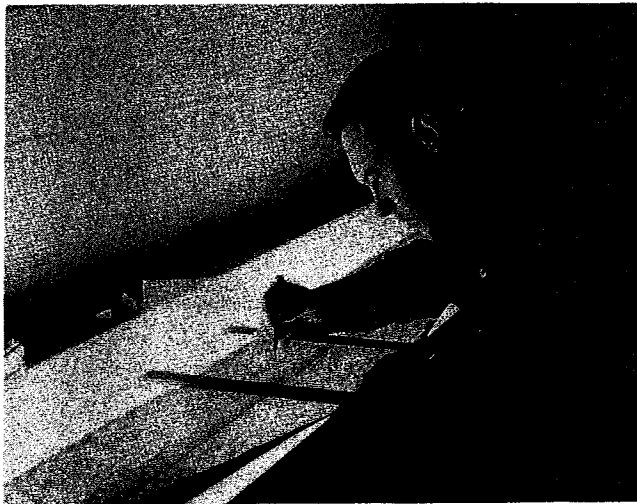
DATA REDUCTION OF STRIP FILM

FIGURE 9
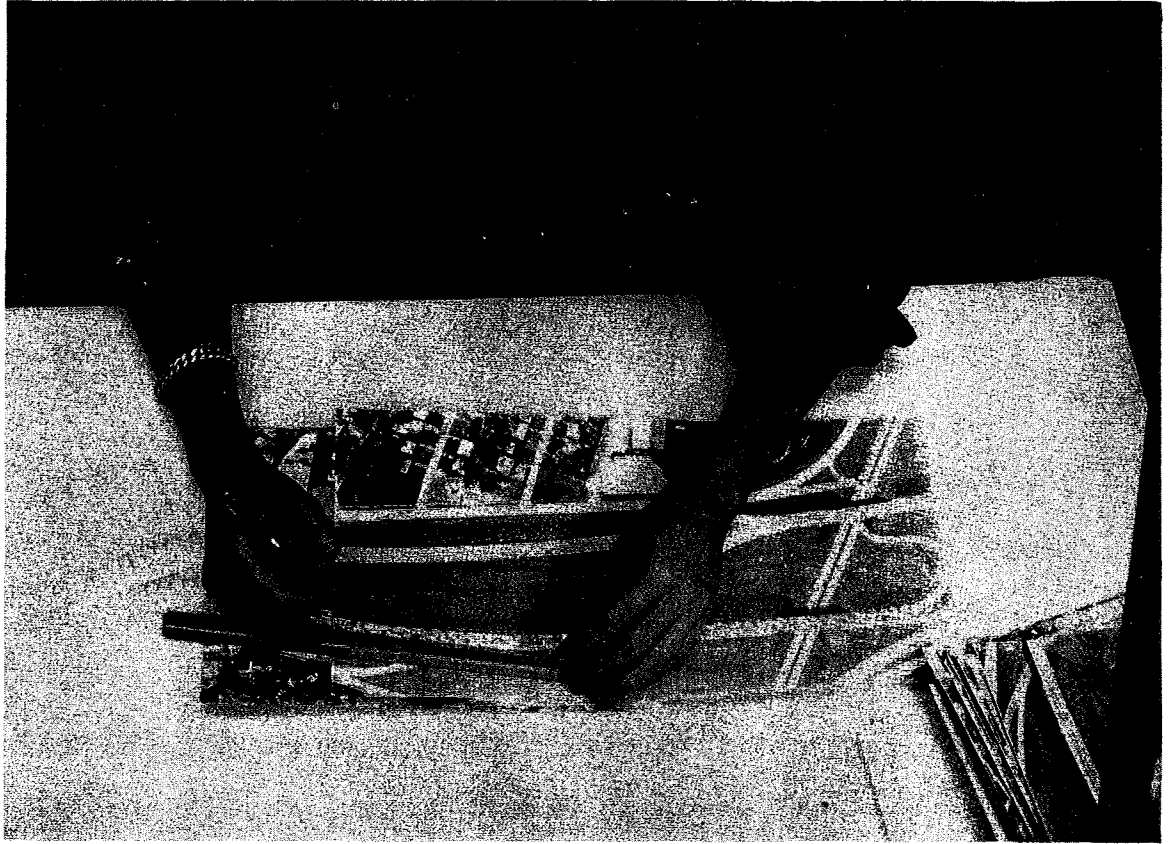
DATA REDUCTION OF TIME LAPSE PHOTOGRAPHY

FIGURE 10

Limited Accuracy of Equipment - The limitations of the equipment make it necessary to estimate measurements to the nearest one-hundredth of an inch. Figure 11, illustrates the error in speed resulting from an error in the readings. Low speeds of 20 miles per hour or less have considerable error in the range of 10 to 15 percent that can be attributed to the limited accuracy of readings.

By employing a stereo viewer or other such equipment, the readings can be obtained to the nearest one-thousandth of an inch. This equipment requires a trained operator.

By magnifying the film, the readings can be estimated to the nearest five-thousandth of an inch with little difficulty, and would provide speed measurements as accurate as data taken by other means.

Variation in Scale - As in all types of aerial photographs, there is difficulty in obtaining a uniform scale on the continuous strip film. However, variations in the scale have no effect on the vehicular speeds, since the scale of the film does not appear in the calculations.

Space headways and vehicle densities can not be measured directly, because of the difference in time of photographing the two vehicles. The correction necessary to position the vehicles in their true relative positions is small for high density conditions. The variation in scale must be considered in determining the original location of each vehicle as it appears on the film.

Variation in Plane Speed - The plane speed was calculated by dividing the length of flight by the elapsed time during the flight. This average speed was assumed to be constant throughout any one flight. This assumption is valid since the plane speed was high and the variations would be only a very small percentage of the true speed. The vehicle speed calculated from the continuous strip photograph is obtained by equating the ratio of vehicle movement to plane movement, to the ratio of vehicle speed to plane speed. Therefore, an error in plane speed would result in the same percentage error in vehicle speed.

Variation in Altitude - The angle between the two camera lenses remains constant, so the only condition which would result in a change in the photograph displacement is a change in altitude. This is one of the most difficult conditions to control and, as a result, the photograph displacement varies constantly.
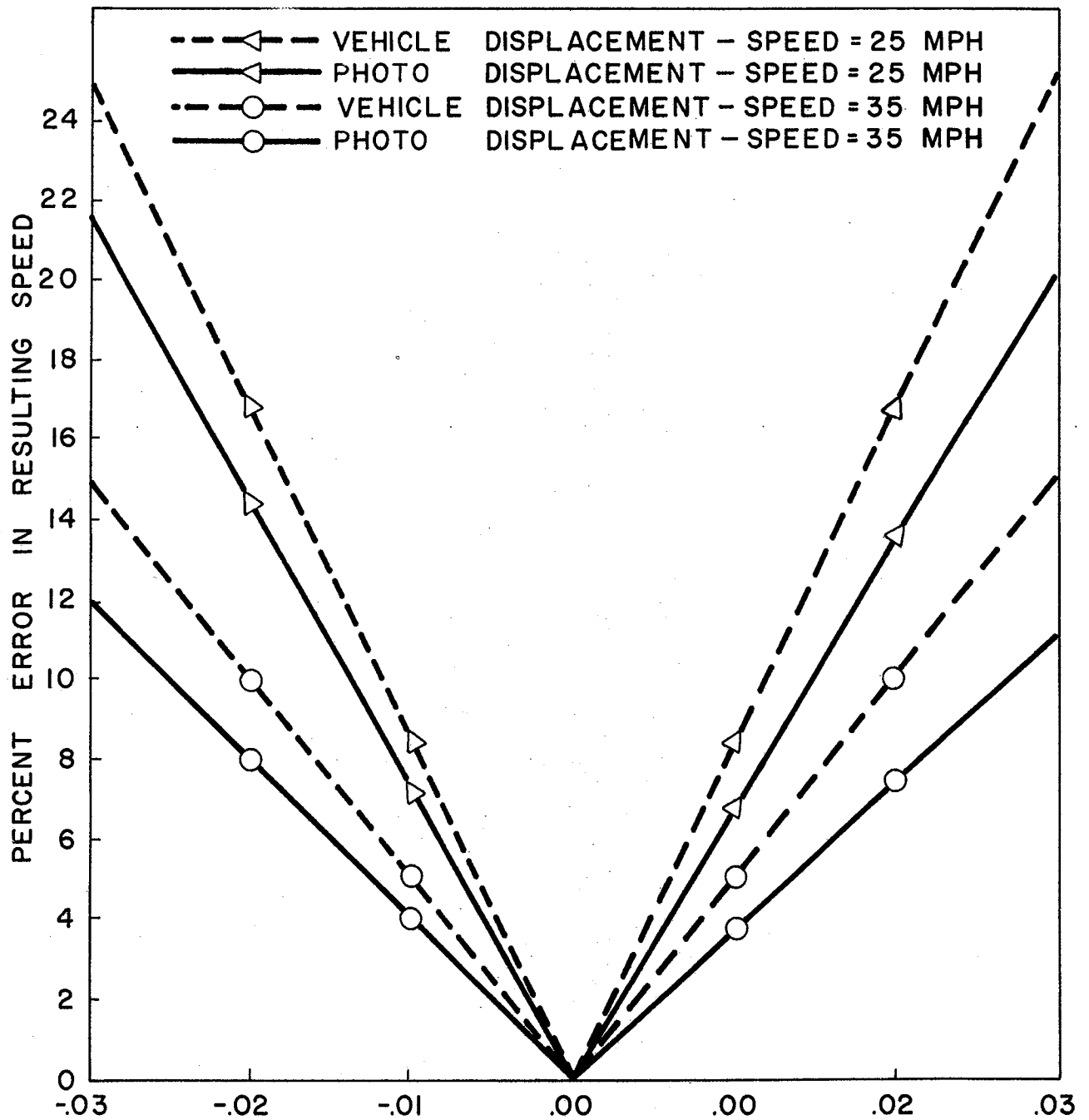
ERRORS IN SPEEDS RESULTING
FROM ERRORS IN READINGS

FIGURE II

It was impractical to take a photograph displacement reading for every vehicle. Readings were taken at every 100-foot station along the roadway and the photograph displacement for each vehicle was obtained from a straight line interpolation of these displacement readings. Using the station numbers as reference points, the same photograph displacement was used for all three freeway lanes.

Measurements of vehicle and photo displacement were made directly from the positive transparencies with a scale etched in a plexiglass overlay. Readings were made to an accuracy of 1/1000th of an inch.

The accuracy of these readings was checked by selecting one hundred 'test' vehicles at random and sending them to the contracted aerial survey company for processing with the stereoscopic viewer. Data were read to 1/1000th of an inch. Three members of the project staff made readings on the same vehicle using the plexiglass overlay.

The data from the survey company were assumed correct and compared to the readings made by the overlay, Table 1. Figures 12, 13, 14, indicate that the results of the 3 test observers were consistantly higher than the readings from the aerial company. The fact that the speed differences were not distributed around a mean difference of zero indicated a bias in the measuring technique, or testing procedure.

A check of the accuracy of the readings made by the aerial survey company was made from a second sample of one hundred vehicles that were sent to the company to be processed. Fifty vehicles were part of the original set of test vehicles. The readings obtained for the 50 duplicated vehicles were different from the original, Table 2.

Since these differences occurred there was no basis with which to determine the accuracy of the test observer readings. However, a comparison was made which indicated the accuracy of the test observer readings, relative to the accuracy of the readings supplied by the aerial survey company.

For this comparison, only the readings of the two test observers which were employed in the actual data reduction were used. One of these two observers was asked to take a second set of readings for the fifty vehicles, as this comparison was based only on the fifty vehicles for which there were duplicate readings.

TABLE 1

Summary of Differences Between
Aerial Survey Company and Test Observers

Reading	Average Difference			Standard Deviation		
	Observer (1)	Observer (2)	Observer (3)	Observer (1)	Observer (2)	Observer (3)
Vehicle Speed (mph)	2.7	1.7	1.7	4.4	7.8	5.0
Vehicle Displacement (inches)	.006	.002	.001	.020	.039	.025
Photograph Displacement (inches)	.040	.037	.036	.021	.022	.020

TABLE 2

Summary of Comparison of Observers

Variable	Mean Difference			Standard Deviation		
	A	B	C	A	B	C
Speed	−.03	.73	−.85	2.33	4.24	4.78
Vehicle Displacement	−.002	.006	−.007	.014	.026	.026
Photograph Displacement	−.009	.001	−.005	.014	.021	.022

A − difference between two aerial survey company readings.

B − difference between two test observers' readings.

C − difference between two readings of Test Observer 1.
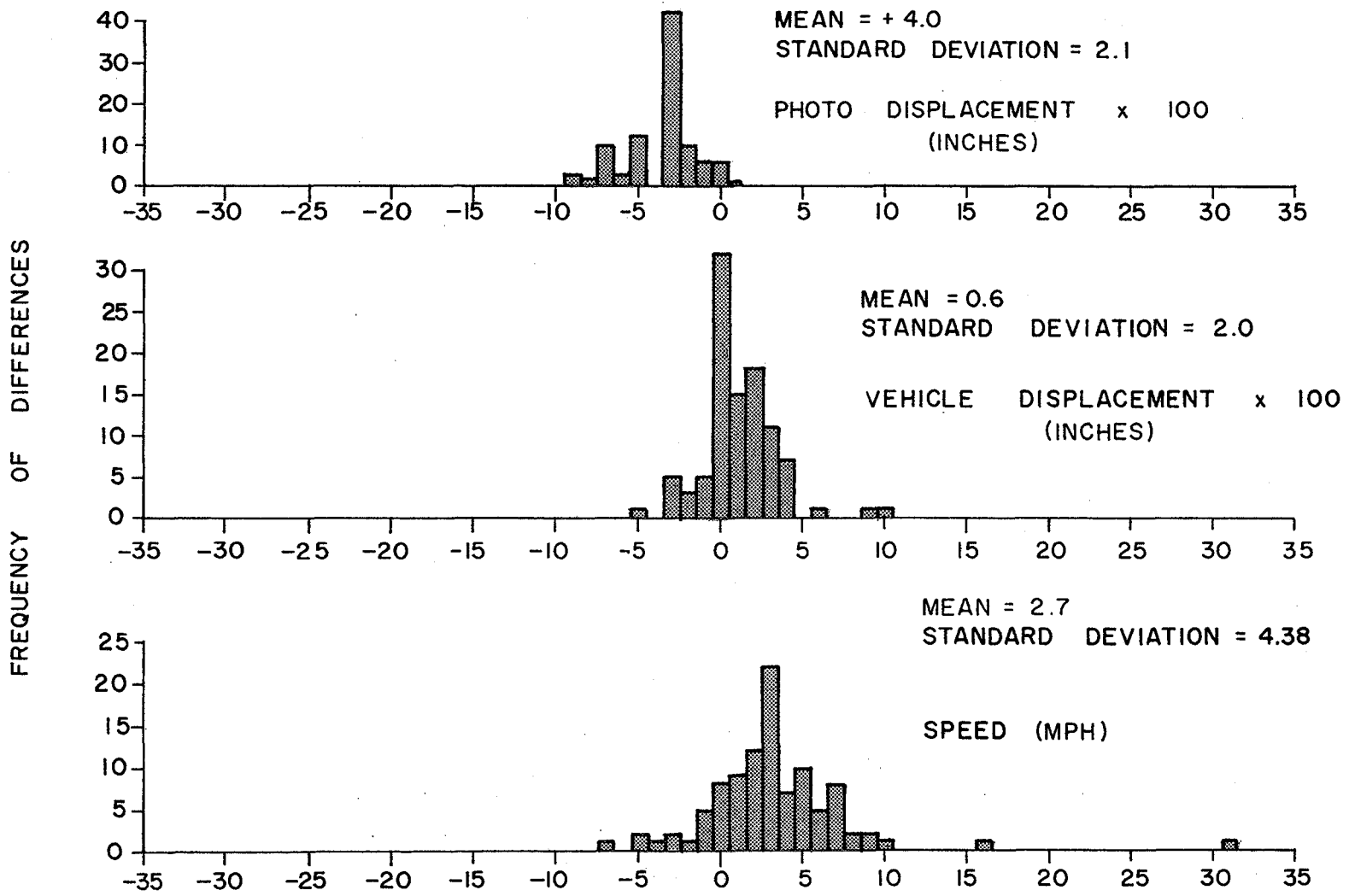
DISTRIBUTION OF DIFFERENCES BETWEEN TEST
OBSERVER I AND AERIAL SURVEY RECORDER

FIGURE 12

MEAN =-3.6
STANDARD DEVIATION = 2.23

PHOTO DISPLACEMENT x 100
(INCHES)

MEAN = + 0.2
STANDARD DEVIATION = 3.9

VEHICLE DISPLACEMENT x 100
(INCHES)

MEAN = + 1.7
STANDARD DEVIATION = 7.77

SPEED (MPH)
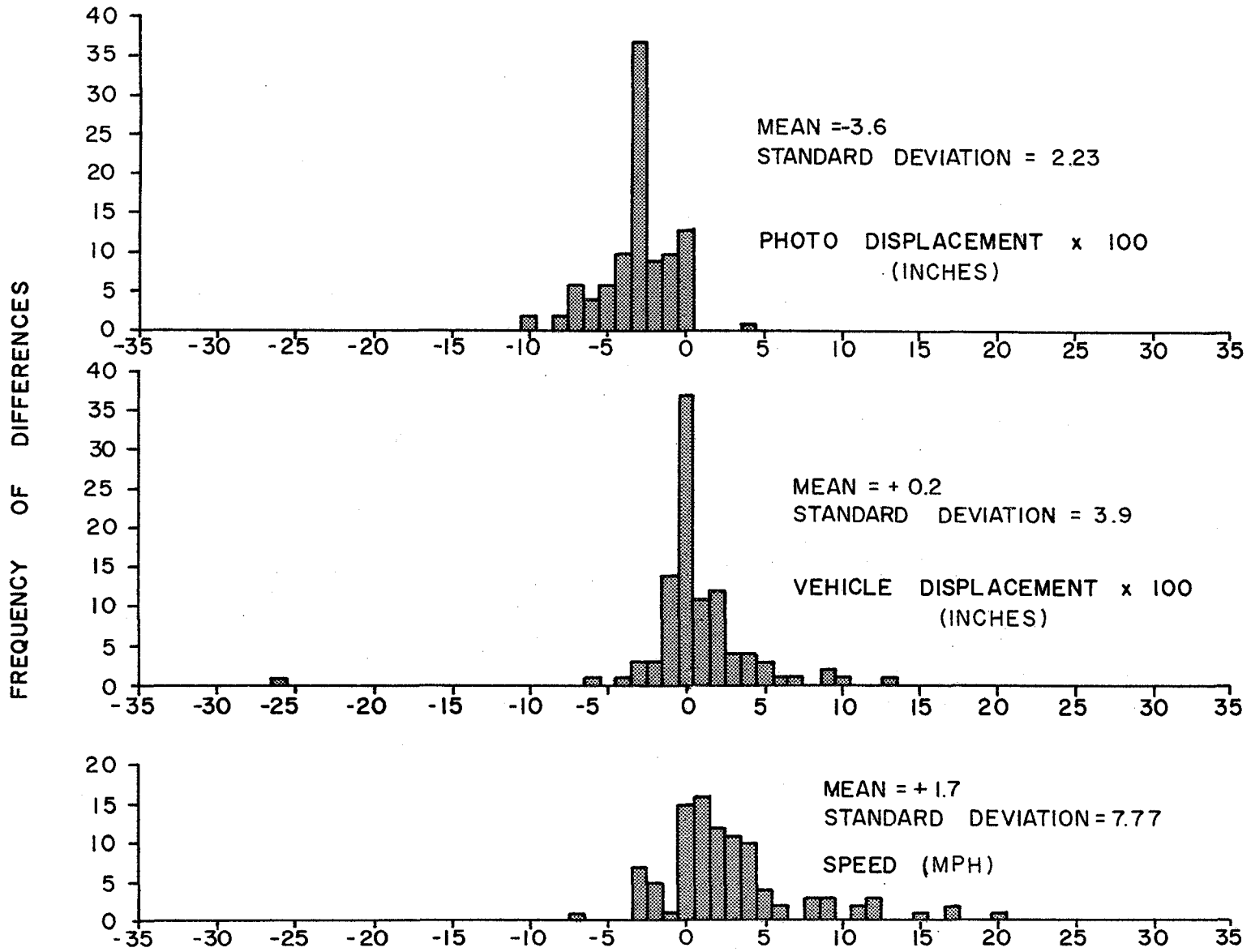
DISTRIBUTION OF DIFFERENCES BETWEEN TEST
OBSERVER 2 AND AERIAL SURVEY RECORDER
FIGURE 13

MEAN = −3.6
STANDARD DEVIATION = 1.98

PHOTO DISPLACEMENT x 100
(INCHES)

MEAN = −.08
STANDARD DEVIATION = 2.5

VEHICLE DISPLACEMENT x 100
(INCHES)

MEAN = 1.7
STANDARD DEVIATION = 5.0
SPEED (MPH)

FREQUENCY OF DIFFERENCES

DISTRIBUTION OF DIFFERENCES BETWEEN TEST
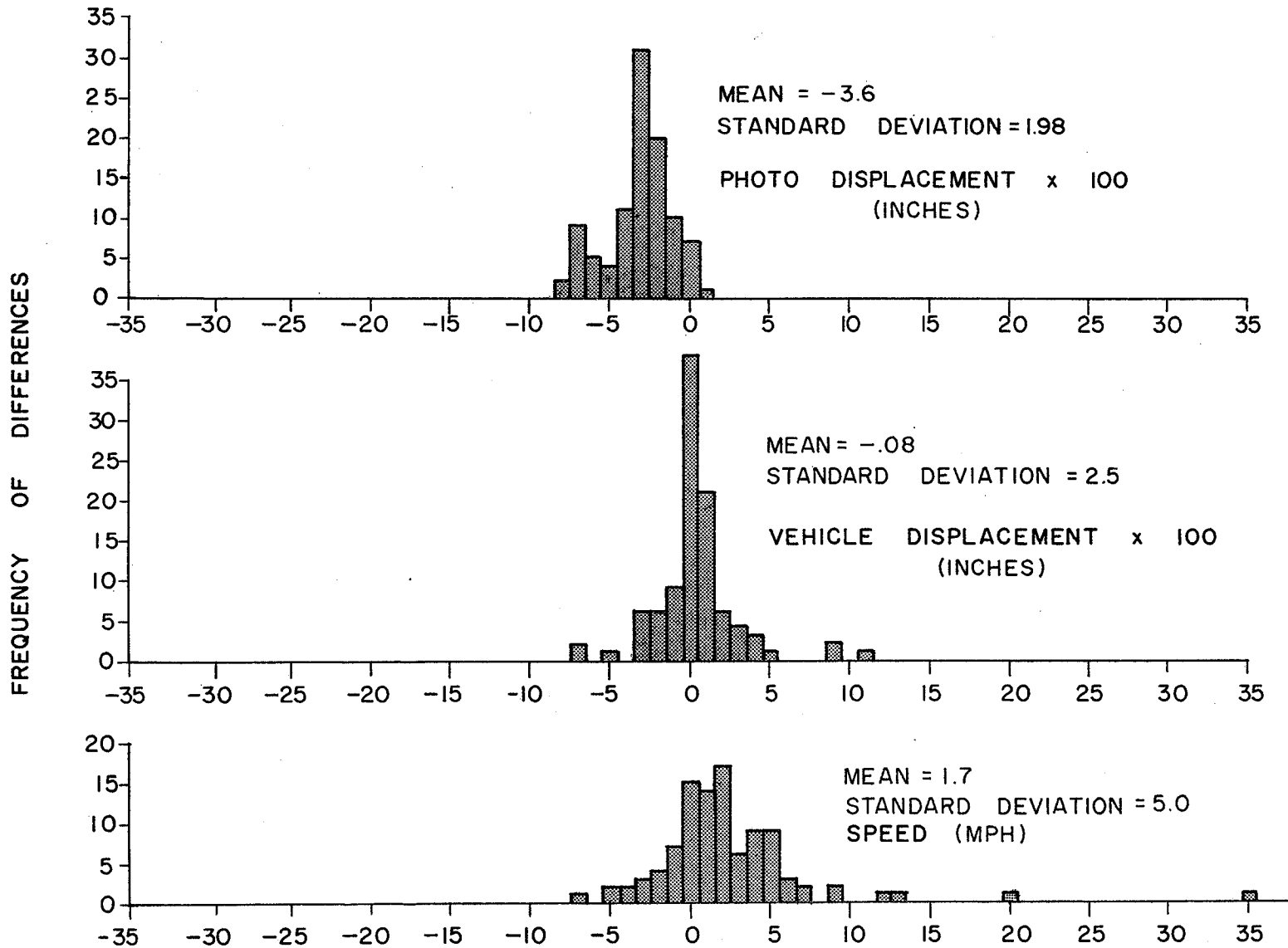OBSERVER 3 AND AERIAL SURVEY RECORDER
FIGURE 14

The differences between the two aerial survey company's the two readings of observer No. 1, and the readings of Observer 1 and Observer 2, were compared and are summarized in Table 2.

Table 2 gives an indication of the degree of reproducibility of the readings. The results of the two observers is about the same as the results of two readings by the same observer. The mean differences in speed of the aerial survey company's readings are considerably less than the mean differences in speed found in the comparison of the test observers. The standard deviation of speed differences, which is the measure of scatter around the mean, was found to be in the range of 4 to 5 miles per hour for the comparisons involving test observers. The standard deviation of speed differences obtained from the readings by the stereoscopic viewer was found to be 2.3 miles per hour.

A fundamental theorem of statistics states that if two distributions are normal, then the sums of differences of these distributions are normally distributed. Therefore, the distribution of these differences can be expected to follow a normal distribution. It could then be expected that about 70 percent of the differences are within one standard deviation of the mean difference. The mean difference is less than 1 mile per hour in all three comparisons.

To give an indication of the type of data used in this comparison, the speeds of the fifty test vehicles have an average of 34.7 miles per hour, and covers a range of 52.6 miles per hour, the maximum being 59.7 miles per hour, and the minimum being 7.1 miles per hour.

Time Lapse Photography

The data taken from the time lapse photographs were subject to the same factors that affected the accuracy of measurements from the strip film. Measurements of vehicle displacement were read to the nearest one-hundredth of an inch with an engineers' scale. The time interval between photographs had an accuracy of ± 0.1 seconds. The maximum effect of these two measurements of the determination on vehicular speeds would be:

$$\pm \ 3 \text{ mph at } 70 \text{ mph}$$
$$\text{to}$$
$$\pm \ 1 \text{ mph at } 15 \text{ mph}$$

The contact prints were scale ratioed so that variations in altitude did not affect the scale.

The only major problem in the data reduction was the transfer and identification of reference points on different photographs. The movement of a vehicle was measured from one distinguishing roadway feature. If this reference point failed to appear in all photographs in which the vehicle was filmed, a new reference point was established. Frequently, the third or fourth vehicle position was located by measuring from the wrong reference marker. A computer program that noted large speed changes was developed to pinpoint these errors.

Measurements from these reference markers were made using an average photograph scale. There was distortion at the edges of the photograph but the errors in distance due to this scale variation were less than 2 percent.

Economic Comparisions

Cost of Field Studies

Because of the general practice of aerial survey companies to negotiate contracts, the cost of a traffic survey such as the one performed in Houston will depend on many factors: The length of the study, the location of the study area, the time of the year and the availability of equipment. The contracts for the Houston Study contained the following provisions:

Strip Photography: "Beginning at 6:30 a.m. the plane shall make as many filming runs as possible until 8:00 a.m. This schedule is to be repeated as soon as possible." This plan resulted in 22 runs covering 5 miles of freeway on each run. One positive film transparency for each run at a scale of 1 inch equals 200 to 300 feet was provided for a total cost of $2,500.00.

Time-Lapse Photography: "Beginning at 6:30 a.m. the plane shall begin making the prescribed filming runs. A total of 9 runs will be completed before 8:00 a.m." One set of scale ratioed prints at a scale of one inch to 100 feet for each run was provided at a cost of $2,300.00.

First indications are that the continuous strip film provided much more coverage for the money expended. However, there are other factors that must be considered. Table Number 3 gives some statistics of the two surveys.

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TABLE 3

	Time-Lapse Photography	Continuous Stereo Strip Photography
No. of Filming Runs	9	22
Altitude of Flights	2,500 feet	1,000 feet
Flying Time	55 min.	2 hr.-55 min.
Filming Time	26 min.	50 min.
Cost of Film Survey	$2,300.00	$2,500.00
No. of Vehicles Observed	7,186	13,774
No. of Speed Readings	15,700	13,774

On the 22 continuous film strips 13,774 vehicles were photographed. Only a few vehicles were filmed on two consecutive filming runs, so most of the 13,774 speed readings were of different vehicles.

Nine of the continuous strips were made at the same time as the time-lapse photography. Therefore, the same number of vehicles were studied during these runs. However, the time-lapse photography recorded many more vehicle speeds per filming run because of the length of roadway covered in each picture (1800 feet) and the sixty percent overlap between photographs. Time-lapse photography has the added feature of tracking vehicles for several seconds. Most of the vehicles were filmed in three consecutive pictures and a few, traveling at high speeds, were recorded in four or five pictures. This represented a time interval of 12 to 15 seconds, during which speed changes could be determined.

Table 4 indicates the cost per mile for the aerial surveys. The continuous strip films provided the least cost in considering the length of roadway covered by the plane, but the unit cost for the length of roadway as measured from the photographs, correcting for the overlap, indicates the time-lapse surveys to be less expensive.

Cost of Data Reduction

Continuous Strip Photography – The continuous strip films were in the form of positive transparencies which require a light table or film reader for viewing. Several different approaches to the problem of data reduction of the aerial films are outlined below. The methods that give the greater accuracy are usually more time consuming and more expensive than other procedures.

Stereoscopic Viewer – A stereoscopic viewer with the capability of making readings to 1/1000 th of an inch was available from the aerial survey company that performed the study. The two alternatives available were to rent the viewer and train a member of the project staff in its use, or to contract the work with the survey company. Estimated costs of each proposal are outlined below:

Renting Stereoscopic Viewer:
      Rental Cost: 6 mo. @ $120.00 1st month
                                   80.00 per additional month
                                                $ 520.00

      Cost of Training Viewer Operator $ 500.00

      Salary for Viewer Operator $1,500.00
                                            $2,520.00
Contracting Data Reduction:
      Cost of Data Reduction
         13,774 vehicles @ $1.25/vehicle = $17,200.00

TABLE 4

Comparison of Cost/Mile
For Aerial Photography

Study	Percent Overlap	Scale	Cost Per Mile Filmed	Corrected for Overlap
Continuous Strip Photography-Houston*	0	1"= 300 ft.	$18.90	$18.90
Time Lapse Photography-Houston*	60	1"= 100 ft.	$41.90	$16.75
Time Lapse Photography-California**	15	1"= 200 ft.	$20.49	$17.40

*Traffic Studies
**Inventory Study

Enlargements of Film Strips - Another approach to improving the accuracy of measurements taken from the continuous film strips was to improve the scale of the film. The Texas Highway Department made available their photographic equipment which has the capacity of enlarging the film strip threefold. Sample prints were made for study. At a 3 to 1 enlargement ratio, fifteen sheets were required for each film strip. The cost for enlarging the entire study would be:

330 sheets @ $4.50/sheet = $1,485.00

Since the film strips were positive transparencies, positive contact prints could not be obtained directly. The cost of a set of negatives would be:

330 negatives @ $1.50/negative = $495.00

Limited studies on the cost of reading the data from the sheets indicate that the man-hour requirement for reading data from these prints was not significantly different from reading data from the original film strip.

Measurements from Film Strips - The technique which was used on this project was to make measurements directly from the film transparency. Cost of Equipment and Personnel used in this data reduction technique are:

Equipment:

2 light tables 60" x 24"	$160.00
2 magnifying glasses	$ 6.00
2 engineers scales	$ 10.00

Data Reduction:

13,774 vehicles @$0.05/vehicle =	$690.00
	$866.00

The cost of data reduction was calculated from a pay rate of $1.00 an hour for student workers. The $0.05 per vehicle rate was determined after the data reduction procedure was well established. The rate includes the cost of reading the station numbers and vehicle displacement for each vehicle and the photo displacement for each station number, recording the vehicle type, lane, and direction of travel. The cost of locating station numbers was approximately $6.00 per film strip. This cost item was not

included in the per-vehicle rate because it is independent of the number of vehicles photographed and because this reduction task can be eliminated by placing markers on the pavement prior to the survey.

Time-Lapse Photography - Measurements of vehicle movements during the time interval between photographs were made directly from the contact prints provided by the aerial survey company. These prints had a scale of one inch equals one hundred feet, which permitted measurements with an engineers' scale to the acceptable level of accuracy.

The cost of data reduction of the time-lapse photography was:

15,700 speed readings @ $0.07/vehicle = $1,100.00

The cost of data reduction was calculated from a pay rate of $1.00 an hour for student workers. The $0.07 per vehicle rate was determined after the data reduction procedure was well established. The rate includes the cost of reading and calculating the station number of the vehicle, the vehicle type, lane and direction of travel. The cost of locating the station numbers is approximately $25.00 per film run. This cost item was not included in the unit cost because it is a reduction task that can be eliminated by placing markers on the pavement prior to the survey.

The cost of data reduction was higher than that of the continuous strip film because of the difficulty in referencing the vehicles to station numbers. Computer programs were written to compute all traffic flow data from the basic information for each vehicle, which was the location of the vehicle and the time of day. Locating the vehicle by station number on each photograph was complicated by the scale distortions at the edge of the photographs and the inaccuracies of the station numbers themselves. Station numbers were transposed on the film from a set of freeway plans. Because of the scale distortions, more than two reference markers should have been used, but on some photographs, there were no distinguishing roadway features to establish as references. This problem can be averted by placing markers on the pavement prior to the survey. Since no additional reference markers were used in this study, a special reduction procedure was used whereby the first vehicle position was determined from the transposed station markers. Each succeeding location was calculated by measurements from a common reference marker. This continuing reference to the photograph in which the vehicle first appeared resulted in a loss of efficiency.

Data Obtained from the Two Aerial Surveys

Speed

Both photographic methods provide means of obtaining vehicle speeds. The accuracy of these measurements are different because of the time interval used to calculate speeds, and the scale of the photographs.

Density

Density must be calculated from the data read from the continuous strip film. The data has to be corrected for the time required to photograph the length of roadway being studied. This correction is very small, in the order to 5 to 10 seconds, for lengths of one or two thousand feet.

The time-lapse photography gives a true reading of density for each picture which covers a section of approximately 1800 feet. Measurements over a longer section require two or more photographs which are separated by short time intervals. In this event the same correction for the elapsed time must be made to determine density.

Space Headways

The determination of the distance between two vehicles, space headways, is subject to the same conditions and corrections that are applied to density measurements.

Time Headways

The time separating two vehicles can be calculated by dividing the space headway by the speed of the trailing vehicle.

Volume

The volume of traffic can be determined from aerial photographs if continuous coverage was maintained for an hour or more. Rates of flow of traffic can be calculated for each filming run from the following expression: [9]

$$V_t = \frac{\bar{s} \, (\, n - 1 \,) \, S_p}{D + (S_p - S_d)}$$

where V_t = rate of flow of traffic in
vehicles per hour for a time
period of $t = D_t/S_p$

$\bar{s}$ = Average overall speed of n vehicles

D_t = Distance between end vehicles
(Scaled from film strip)

n = Number of Vehicles in Distance, D_t

S_p = Speed on the Plane in M.P.H.

S_d = Speed of last vehicle in line

The determination of n must be done carefully to avoid counting the same vehicle more than one time.

Acceleration - Deceleration

Speed change by individual vehicles cannot be measured by the continuous strip film. Each vehicle is photographed only twice each run.

The time-lapse method of aerial photography can provide multiple readings of speed for each vehicle. There are several factors that influence the number of times a vehicle will be photographed:

1) the percent overlap between successive photographs.

2) the difference in airplane and vehicle speeds.

3) the direction of flight relative to the direction of the traffic stream.

In the survey made in Houston 60 percent overlap and a plane speed of 120-140 mph resulted in several vehicles traveling in the same direction being photographed five times. From these several measures of speed the acceleration and deceleration of the vehicle can be calculated. These speed traces can be of value in measuring the build up, or relief, of congested areas.

These measures of speed change can also be used in the calculation of density. Rather than making the assumption of constant speed, the acceleration or deceleration of the vehicle can be projected for the time interval involved to get a more accurate location for density determination.

Vehicle Classification

Large commercial vehicles can be identified from both the continuous strip films and the time-lapse photographs. Small single unit and pick-up trucks are difficult to distinguish from passenger vehicles on the strip film, especially when the traffic is moving fast.

Markings, placed on the top of the control vehicles, were easily noted in the time-lapse film, but required very close inspection of the film strips.

IV

CONCLUSIONS

The application of aerial photography to traffic studies has been demonstrated and has proven to be an excellent means of gathering traffic data. Through the use of this technique the study areas have been expanded in breadth and length and observations of traffic operations on the street system that supports the freeways are now possible. Traffic flow characteristics that require measurements of distance, such as density and space headways, can be determined more accurately.

There are disadvantages as well that must be considered in the design of a traffic study by aerial photography. Although the traffic conditions are recorded pictorially in a true relation to the geometric design of a facility, aerial photography does not provide the continuous coverage in time that is characteristic of the motion picture studies. This fact should be carefully considered in the determination of the length of study section and the frequency of the flights.

Data reduction of aerial photographs is still a time consuming task. But a computer program that utilizes only a few basic measurements to calculate all traffic flow characteristics eliminates the necessity of reviewing the photographs time after time.

Aerial photographic studies are limited to times of good lighting and flying conditions. This prevents the study of peak hour traffic during winter months under the worst driving conditions.

The selection of the type of aerial photography to use requires consideration of the information that is to be taken from the film. The following conclusions are drawn from the aerial surveys made in Houston:

1. Time-lapse photography is more suited for density measurements. Pictures should be taken at an altitude that will give coverage over the length of roadways to be used in the density calculations. The degree of photograph overlap can be adjusted to the requirements of the study.

2. Time dependent parameters can be measured more readily from the continuous film strips.

3. Vehicular speed changes can be measured from the time-lapse photographs.

4.   Land distribution and vehicle classification can be taken from both methods, but vehicle identification from the continuous strip films is more difficult because of the blurred images.

5.   When freeway sections of less than 2000 feet are studied, the effect of time lag in the continuous strip film is slight. The assumption of uniform speed gives results within an acceptable level of accuracy.

6.   Continuous strip film gives more coverage for the money expended: Twenty-two filming runs and three hours of true time by the strip films; nine filming runs and one hour of true time by the time-lapse photography.

7.   More speed readings were obtained by the time-lapse photography.

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