The Starting Characteristics of Automobile Platoons

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Abstract

The results of a series of experiments carried out to determine the starting characteristics of automobile platoons are reported. In particular, the space-time trajectories of the lead and last vehicles have been examined in detail in order to determine the macroscopic properties of vehicular platoons. The effects of such factors as initial intervehicle spacing, speed, starting delay, and acceleration behavior are presented. In addition, calculations have been made for the flow of the platoon as a function of position along the roadway as well as for the speed of propagation of the starting wave as the platoon accelerates up to speed.

Introduction

In a recent study,[1] the authors examined the transient characteristics of bus platoons. The motivation of that earlier work was to shed some light on the dynamics of a bus system operating much like that of a train or subway where platoons of buses would start and stop at stations along an exclusive right of way. From these studies it was found that the cyclic dynamics of bus platoons starting at one station and stopping at another possessed repeatable features which could be described relatively simply. The present paper in which we focus our attention on the transient characteristics of automobile platoons is an outgrowth of this earlier work. There is little doubt that the dynamics of a platoon of vehicles discharging from a queue at a signalized intersection play an important role in saturation flow and intersection capacity, and therefore are an important element of the traffic complex in urban areas.

Several studies have been reported on different facets of the dynamics of automobile platoons. For example, Foster[2] examined the starting phase of queues of vehicles immediately downstream from a signalized intersection. From trajectories averaged over a number of cycles, an estimate of the speed of propagation of the starting wave was made. Other investigators[3-6] have also studied various characteristics, such as flow, speed, and dispersion, of platoons discharging from signalized intersections. In addition, Herman and Rothery[7] have studied the dynamics of the transition of a vehicular platoon going from one steady state to another.

In the present work we are concerned mainly with the starting dynamics of a queue composed of similar automobiles on a test track facility. In particular,

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our efforts are directed towards studying the initial starting delay, the starting wave as it propagates back through the platoon, a description of the dynamics of starting as well as the transit time of platoons moving past an observation point as a function of distance down the roadway.

In the next section we discuss the techniques that were used in carrying out these experiments.

Experimental Details and Techniques

A platoon of six automobiles was used throughout the studies. These vehicles were standard, full-size production model 1970 Chevrolets with the exception of the lead vehicle which was a standard full-size Oldsmobile. This latter vehicle housed all of the recording equipment.

The roadway used was the four lane divided test track facility located at the General Motors Technical Center. The test track is approximately 1¼ miles long including turn arounds at each end. Only the straight section was used for each test run and the platoon was confined to one lane in each direction. This facility thus provided a straight, wide and level road section, with no entrances, exits or cross roads, 0.7 of a mile long.

The lead vehicle was controlled by the same driver in every test run. He was provided with a monitor that displayed the acceleration of his vehicle and was instructed to accelerate his vehicle at a nearly constant rate to a predetermined speed. The five other vehicles were also driven by employees of the General Motors Research Laboratories. They could not, in any way, be considered professional drivers and were not selected because of any particular attribute. Their position in the platoon was changed each of the five days that were required to complete the total number of test runs. The only instruction given to these drivers was to "follow the vehicle ahead in a 'normal' and 'safe' manner."

Ninety-eight test runs in all were recorded which provided approximately 11 repeated trials for each combination of the two control parameters. These control parameters were the maximum attained speed of the lead vehicle, u_0, and the mean acceleration, $\bar{a}$, used by the lead vehicle to attain this speed. Three levels were used for each variable. Table I gives the matrix of the experimental conditions investigated and the number of repetitions of each condition. The chronological order of the runs for the various combinations of speed and acceleration was sequenced by a quasirandom scheme.

The acceleration control variable requires special comment. The initial objective was to have three levels for the mean acceleration of the lead vehicle with the specific values of 4, 8, and 12 ft/sec^2. Operationally, this was not achieved. First of all, the lead vehicle's performance was below that of a standard vehicle due to the abnormal loading caused by the electronic equipment that was housed in it. This reduction in performance was particularly detrimental to the runs calling for the highest acceleration. The resulting average acceleration of the lead vehicle for this high acceleration case was ~9.18,

TABLE I

The Control Variables Used in the Experiments: Mean Acceleration, $\bar{a}$, and Final Cruising Speed, u_0, of the Lead Car. The entry in the Table is the number of runs for each condition.

	u_0	30 (mph)	40 (mph)	50 (mph)
	Low	11	11	11
$\bar{a}$	Medium	9	12	12
	High	11	10	11

~8.52, and ~7.73 ft/sec^2 for the three speed levels of 30, 40, and 50 miles/hour, respectively.

Throughout each test run magnetic tape recordings were made of the motion of the lead vehicle and the last vehicle of the six-vehicle platoon. These recordings consisted of the time series of events for every foot of forward motion of each instrumented vehicle. This information was obtained by using fifth wheels. The positional information from the last vehicle was transmitted via a telemetering link to the lead vehicle and was recorded on magnetic tape simultaneously with similar information obtained from the lead vehicle as well as a 3000 cycles/sec synchronizing clock signal.

The information recorded during the experiments was later reduced to a digital format by accumulating the time taken by each vehicle to travel a distance of 14 ft. In order to measure starting times, the time at which the first forward foot of motion was completed was also obtained for the lead and last vehicles.

The data was processed by an IBM 360 Model 65 computer to obtain trajectory information interpolated at equal ¼ sec intervals. Speed, platoon length and relative speed histories were also obtained in both numerical and graphical form (see Fig. 1 of Ref. 1).

A number of analyses were performed on the basis of this data, the results of which are discussed in the next section.

Results

Transient Characteristics of Starting

The transient characteristics of a vehicular platoon from the time the platoon starts to move to the time it reaches a steady state can be separated into two phases: the acceleration phase defined from the time the lead car starts to move to the time the last car reaches the cruising speed of the lead car; and the relaxation phase defined from the end of the acceleration phase to the time the platoon reaches a steady state. These two phases of the starting transient are

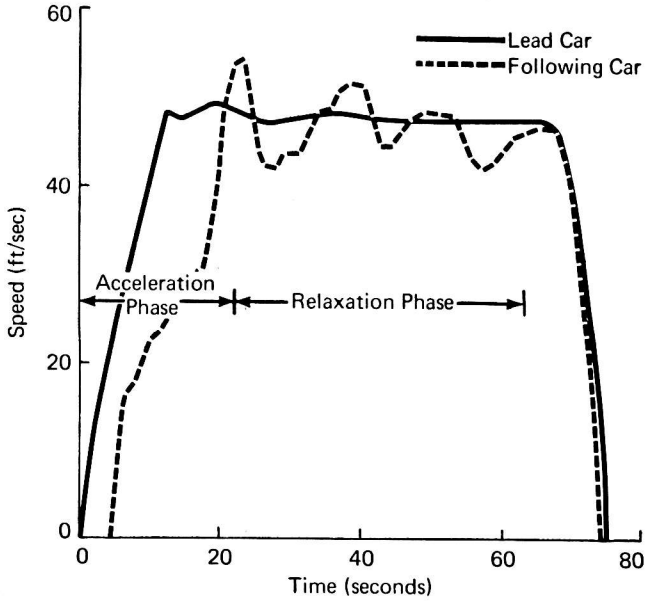

Fig. 1. Speed histories of the lead and last cars for a typical test run. Low acceleration a 30 mph maximum speed were used by the lead car in this case. The acceleration phase a the relaxation phase of the starting transient are indicated.

illustrated in Fig. 1 which is a typical test run in which the lead car used low acceleration to attain a 30 mph cruising speed. The dynamical characteristics of the platoon during the acceleration phase is discussed in this section and th relaxation phase is discussed later.

The acceleration phase of the platoon can be described by the initial platoon length, the starting delay, the acceleration of the lead car, and the acceleration the sixth car. Such parameters from each of the experimental runs have been analyzed in terms of their averages and variances and with respect to the accele tion and the cruising speed of the lead car. Given these parameters an overall description can be obtained for the platoon during the acceleration phase.

The initial platoon length was the spacing between the same points, e.g., rear bumper to rear bumper, on the lead and last cars at the beginning of the test run. Since no instruction was given to the drivers regarding how they should space their cars, this initial platoon length can be interpreted as the sum of the normal spacings used by the five following drivers when they approach an inte section at low speed (≈20 mph) and then stop. The initial platoon length in the 98 test runs has an average of 129.62 ft and a standard deviation of 5.97 ft This gives an average spacing between pairs of vehicles of 25.92 ft with a standard deviation of 2.57 ft. In order to establish its generality, this result has be compared with the initial spacings of a four-car platoon in a preliminary experi

ment with 15 test runs that involved a different set of drivers. The average spacing from these two different sets of experiments show no statistically significant difference.

The averages and standard deviations of the starting delays for the nine experimental conditions are shown in Table II. The results of an analysis of variance on the starting delays give an indication that the starting delay depends on the acceleration of the lead car (at the 0.5% significance level) but not on the final cruising speed (at the 10% significance level). Since at the time the sixth car started to move the lead car was still accelerating, even for the 30 mph cases, the starting delay in these experiments is thus expected not to depend on the cruising speed of the lead car. However, the result may be different if the cruising speed of the lead car were sufficiently low or the platoon size were large. After the starting delays for different lead-car cruising-speed cases have been combined,

TABLE II

The Averages and Standard Deviations (in parentheses) of the Starting Delays (in sec) for Each Experimental Condition ($u_0, \bar{a}$)

	u_0	30 (mph)	40 (mph)	50 (mph)	All speeds
		(sec)	(sec)	(sec)	(sec)
$\bar{a}$	Low	5.35 (1.08)	4.77 (0.65)	4.74 (0.55)	4.95 (0.82)
	Medium	4.62 (1.22)	4.25 (0.70)	4.44 (0.96)	4.44 (0.95)
	High	4.29 (0.68)	3.98 (0.79)	3.97 (1.00)	4.08 (0.82)

the results of Behrens-Fisher tests show the difference of the mean starting delays between low and medium acceleration cases to be significant at the 2.5% level; between medium and high acceleration cases to be significant at the 10% level; and between low and high acceleration cases to be significant at the 0.5% level.

The mean acceleration as a function of speed has been calculated as the ratio of a given speed and the time that it took the vehicle to reach that speed from a standing start. The mean acceleration averaged over runs of the same controlled conditions is shown in Fig. 2 for the lead and the last car and for the nine conditions of lead car acceleration and cruising speed. Also shown together with the averages are the 99% confidence limits on the averages.

The acceleration of the lead car is one of the control variables of the experiment. In the low acceleration cases, the lead car was able to maintain consistently a mean acceleration of about 4 ft/sec^2, as intended, with only small variations from run to run. Although the mean acceleration was a little higher than the instructed value when the vehicle started to move, the variation from run to run

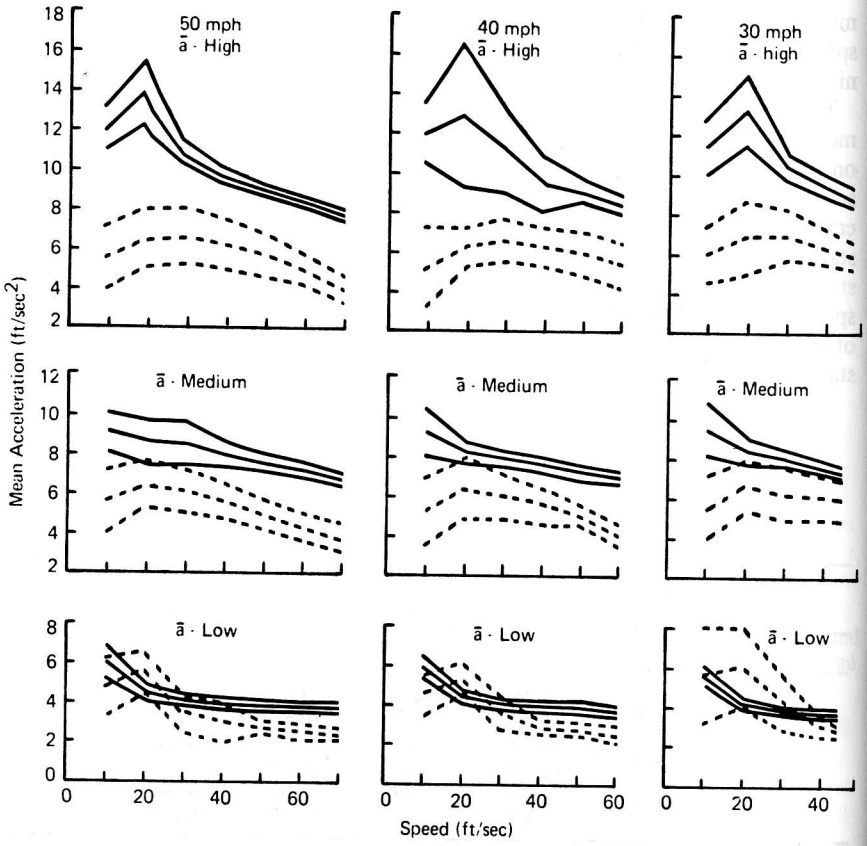

Fig. 2. Averages of mean accelerations calculated from a standing start to various intermediate speeds versus intermediate speed. Also shown are the 99% confidence limits of the averages. The solid curves are for the lead car and the dashed curves are for the last car. Each graph shows the results for one of the nine experimental conditions.

was small and the mean acceleration intended was very quickly reached and maintained. In the high acceleration cases, due to the affect of the equipment on the instrumented lead car, the intended accelerations of 8 and 12 ft/sec^2 could not be maintained when the vehicle reached higher speeds. However, as can be seen in Fig. 2, two distinctly different acceleration characteristics were produced by the lead car for the medium and high acceleration cases. Although the variations in the acceleration characteristics were large from run to run at low speeds, the mean acceleration became quite consistent by the time the lead car reached higher speeds. In other words, the mean acceleration of the lead car from a standing start to the specified cruising speed was replicated well from run to run for each of the acceleration conditions.

The mean acceleration of the last car has, in general, larger variation between runs of the same condition than the lead car. The variations from run to run were, however, drastically reduced at speeds of 40 ft/sec or higher implying that most of the variation occurred at speeds lower than 40 ft/sec. Such variations at low speeds, which will be discussed later, were averaged out by the time the last car reached higher speeds.

Comparing the mean accelerations of the last car for runs with the same lead-car acceleration but different cruising speeds, it can be seen that the mean accelerations of the last car as a function of speed are similar in that portion of the curves where they overlap in speed. This result is expected because the last car driver did not have information of the final cruising speed of the lead car. He adopted the cruising speed of the lead car only when this information was propagated to him through the car immediately in front of him. With the averages of three different samples agreeing, this result further demonstrates the consistency (in the sense of averages) of the mean acceleration characteristics of the last car in runs with the same lead car acceleration condition. Furthermore, the mean acceleration of the last car for medium and high lead-car acceleration cases is only slightly different despite quite different mean acceleration characteristics for the lead car in the two cases.

In the high and medium lead car acceleration cases, the mean acceleration of the last car was always below that of the lead car; whereas in the low acceleration cases, the mean acceleration of the last car at speeds between 10 and 20 ft/sec exceeded that of the lead car in most of the test runs. Mean accelerations were not calculated for speeds below 10 ft/sec because the first data point available was the travel time of the first 14 ft made by the vehicle. The average speed for the first 14 ft traveled was already greater than 10 ft/sec. Where the mean acceleration of the last car exceeded that of the lead car it was quickly corrected by the last-car driver to a level below that of the lead car by the time the last car had reached approximately 30 ft/sec.

Despite the consistent average acceleration behavior of the last car as illustrated in Fig. 2, the detailed speed history of the last car was quite different from one test run to another. Such variations are attributable primarily to the adjustments made in the acceleration of the last car during the early part of the acceleration phase. For most runs where it appeared that the driver of the last car was using too high an initial acceleration, the last car showed adjustments in its acceleration at speeds below 40 ft/sec. Since there was no information recorded for the dynamics of the four intermediate cars of the platoon, the observed behavior of the last car could be a response to disturbances created in the platoon and propagated to it, as well as a result of adjustments to the last car driver's individual action. Such acceleration adjustment may vary from a sharply defined discontinuity in the speed history to a slow continuous reduction in acceleration. Figure 3 shows the speed histories and the phase plots of the speed of the last car versus the platoon length for two runs to illustrate the two extreme types of acceleration adjustments made by the last car.

The acceleration adjustments made by the last vehicle of a vehicular platoon

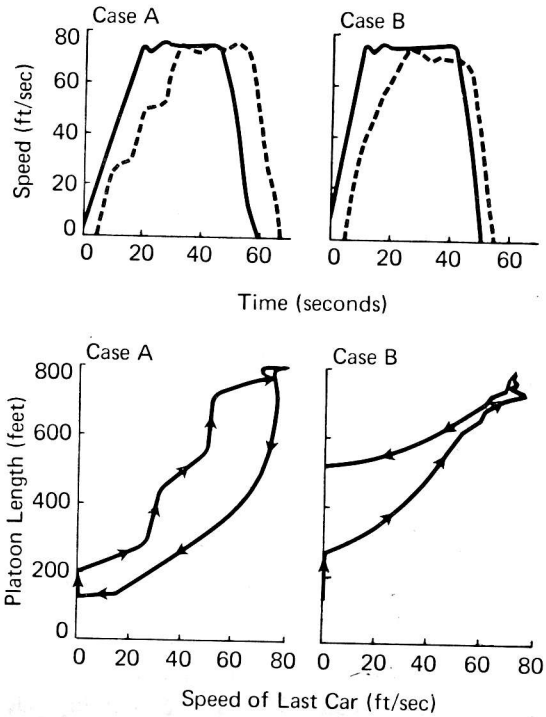

Fig. 3. Speed histories of the lead and last cars and the corresponding plot of the speed of the last car versus platoon length are given for two test runs. In both cases the final speed of the lead car was 50 mph. The lead car used low acceleration in case (A) and high acceleration in case (B) to reach the final speed. In case (B), the last car did not join the platoon at the end of the test run, but instead stopped at a pre-designated position for fifth wheel calibration.

during starting was first studied with a bus platoon. The result of that study[1] showed the sixth bus of the platoon making acceleration adjustments when the platoon reached a certain critical state expressed as a transition region on a plot of the speed of the last bus versus platoon length. Whenever such an acceleration adjustment occurred, it was a well defined one-step correction. Because of the low acceleration capability of the buses, the lead bus, in those experiments, used maximum performance to reach the final cruising speed and the last bus used an acceleration almost identical to that of the lead bus in its initial phase of acceleration. The dynamics of the bus platoon thus had very high repeatability from run to run. Furthermore, since at most one distinct acceleration adjustment was necessary to allow the last bus to reach the final cruising speed of the lead bus, the occurrence of such acceleration adjustments was also highly predictable.

The transient characteristics of the automobile platoon during the acceleration phase of starting are far less predictable. Although the lead car could replicate

its programmed accelerations quite well, the acceleration capability of the automobiles was much higher than the buses, thus giving the following cars flexibility in accelerating into the same near-steady-state platoon configuration at the time the platoon reached the specified cruising speed. The reproducibility of the dynamics of an automobile platoon during the acceleration phase of the starting transient was therefore reduced. However, as indicated in Fig. 2, most of the variations occurred at low speeds over which the automobiles have the highest acceleration capability.

The adjustments made by the last car driver on the acceleration of his vehicle also showed higher variability than those observed with the bus platoon. Unlike the adjustments observed for the bus platoon, there was often more than one distinguishable acceleration adjustment made by the last car before it reached the final cruising speed of the lead car; or there could even be a continuous adjustment in the acceleration. Nevertheless, it was possible to obtain a few general qualitative results regarding the acceleration adjustments made by the last car. Table III shows, for each of the experimental conditions, the number of runs where a discontinuity in the speed history of the last car was observed during the acceleration phase. Also shown in the same table are the number of test runs and the average number of distinct acceleration reductions for those runs where such acceleration adjustments were made. Acceleration adjustments occurring after the lead car had reached its final cruising speed were not included, for it was not clear whether such adjustments were related to features in the acceleration phase or they were responses to the disturbance created by the lead car when it discontinued its acceleration. It can be seen in Table III that whenever the lead car used low acceleration the last car made at least one acceleration reduction prior to reaching the final cruising speed. Such adjustments were absent in runs with high lead-car accelerations. This phenomenon is undoubtedly related to the last car using accelerations higher than that of the lead car in low acceleration cases, as discussed before.

TABLE III

The Number of Runs in Which Acceleration Adjustments Occurred Expressed as a Ratio of the Total Number of Runs for Each of the Experimental Conditions and in the Parentheses the Average Number of Corrections Per Run for Those Cases Where Such Adjustments Took Place.

	u_0	30 (mph)	40 (mph)	50 (mph)
$\bar{a}$	Low	10/11 (1.5)	11/11 (1.5)	11/11 (1.8)
	Medium	0/9 (–)	3/12 (1.0)	10/12 (1.0)
	High	0/11 (–)	0/10 (–)	0/11 (–)

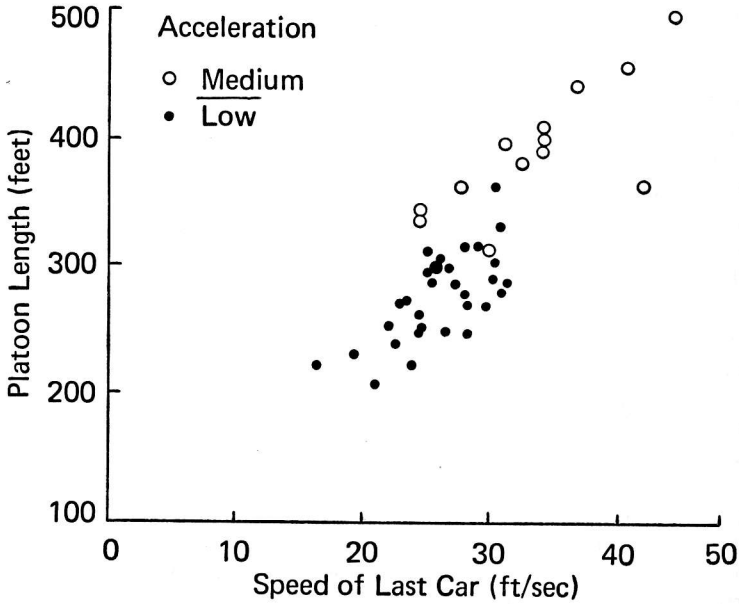

Fig. 4. Platoon length versus speed of the last car at the time the last car initiated its first acceleration adjustment.

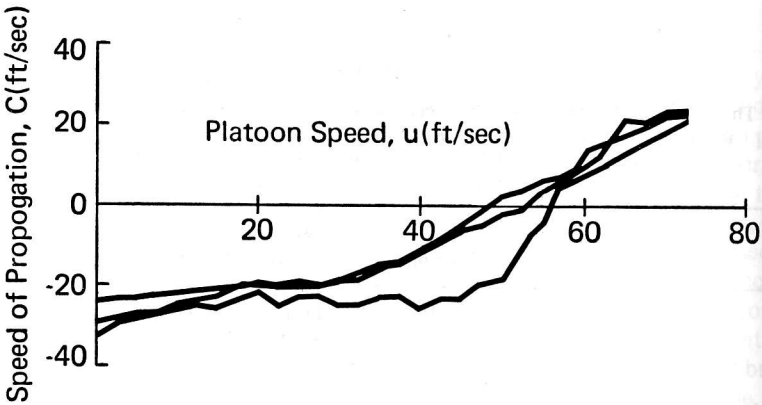

Fig. 5. The speed of propagation, C, of the starting wave versus platoon speed, u, for three individual test runs where the lead car used high acceleration to reach the speed u_0 of 50 mph.

The transition points, at which acceleration adjustments of the last car were made, in terms of the speed of the last car and the platoon length are plotted in Fig. 4 for the first acceleration corrections. It can be seen that practically all these first transitions took place at last-car speeds of less than 30 ft/sec for low lead-car acceleration cases and less than 40 ft/sec for medium lead-car acceleration cases. The locations of the transition points on this graph indicate that the acceleration corrections in runs with low and in runs with medium lead-car accelerations occurred at different platoon configurations. If the difference in vehicle lengths were taken into consideration, the results shown in Fig. 4 for the six car platoon are similar to the transition region obtained for the six bus platoon (see Fig. 8 of Ref. 1).

Speed of Propagation of the Starting Wave

In this section we are concerned with estimating the speed of propagation of the starting wave. In particular, we have calculated from all of the test runs for the case u_0 = 50 mph the quantity C which is the speed of the transition bringing the sixth vehicle up to a speed u. The calculations have been made using the roadway as a frame of reference and therefore C corresponds to the 'standard' definition of the speed of propagation of a transition as defined, e.g., by Lighthill and Whitham.[5] If hydrodynamical theories are applicable for this case, the numerical values for C would be equivalent to the slope of a flow versus concentration diagram, i.e., dq/dk (see Discussion on pp. 14–15 of Ref. 5).

Our estimates for C have been made for each test run at increments of 2.5 ft/sec. Each estimate is made by noting the elapsed time, Δt, between the lead and last vehicle reaching a speed, u; the distance between the positions of the vehicles on the roadway, Δx, where these events occur; and taking the ratio $\Delta x/\Delta t$.

The results for several test runs of the high acceleration case are shown in Fig. 5. It should also be mentioned that the initial starting wave, i.e., C at $u \simeq 0$ is also given in Fig. 5. This latter estimate was made by noting the elapsed time between the first forward foot of travel of the lead and last vehicle and the initial platoon length, L_0. We have termed this starting interval as the 'starting delay' and denote it by T_0.

The cases shown in Fig. 5 were selected as being representative of the types of results that were obtained. The results derived by averaging over all runs for each acceleration condition are shown in Fig. 6. Superimposed on this figure are the results of Foster[2] who calculated C for the starting wave of platoons discharging from a signalized intersection. Foster's experimental technique was to estimate the trajectory of each vehicle from arrival times at six positions spaced at 50 ft intervals downstream from the intersection and to estimate the slope (i.e., speed) of the average trajectory of each vehicle in the platoon. From this information he calculated C as a function of u. In particular the solid line in Fig. 6 is the result of a least squares fit of the equation

$$C = u - \bar{\lambda} \tag{1}$$

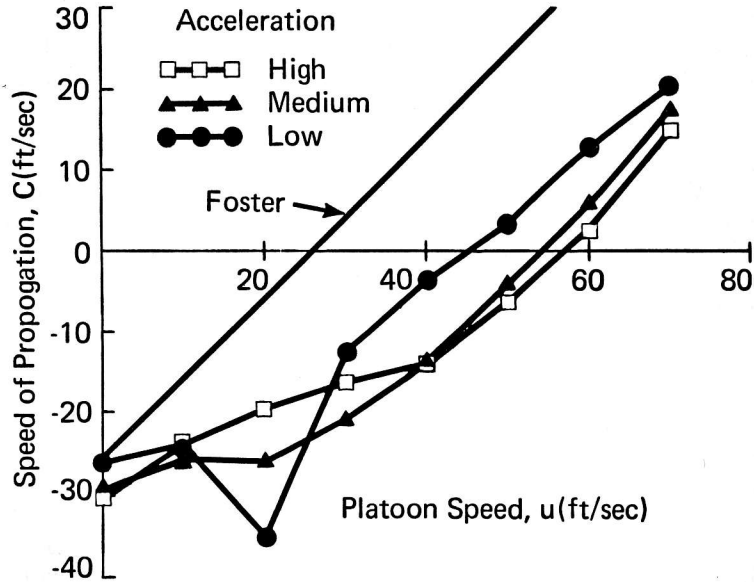

Fig. 6. Speed of propagation, C, of the starting wave, versus platoon speed, u. Each curve is derived by averaging over all runs of the same lead car acceleration. The maximum speed for the lead car in these cases was 50 mph. The result obtained by Foster is also shown.

to his data. The value of $\bar{\lambda}$ was estimated by Foster to be 25.7 ft/sec. Equation (1) simply states the algebraic relationship between the speed of the traffic stream, u, and the speed of propagation of a disturbance with respect to the roadway, C, and the speed with respect to the moving traffic stream, $\bar{\lambda}$. While Eq. (1) is valid for small fluctuations, it is not appropriate for our case where we have large perturbations. Here we have a substantial change in platoon length during the propagation time Δt. If complete information were available on each vehicle trajectory one could trace the propagation of a disturbance more accurately and possibly circumvent this problem.

One of the most interesting features of Fig. 5 showing C versus u is that in a large number of cases the curve for a given test run initially begins with a plateau or at least as a slowly changing function of speed up to a speed of about 30 ft/sec. A constant value of C would imply that the lead and last vehicle trajectories were the same, apart from a translation in space and time to take into account the initial delay time and the initial platoon length. Above the platoon speed of 30 ft/sec, the data fitted to Eq. (1) approximates the relationship between C and the platoon speed u. A "least-squares" fit of Eq. (1) to the data shown in Fig. 6 above 30 ft/sec provides an estimate of $\bar{\lambda}$. These estimates of $\bar{\lambda}$ for the low, medium, and high acceleration cases are 46.7, 53.5, and 55.6 ft/sec, respectively.

Flow Characteristics of the Platoon

The dynamics of the automobile platoon in the relaxation phase of the starting transient have been studied through observations of the transit time of the platoon passing fixed points along the roadway. Observations of this type have been studied previously in Refs. 1, 3-5. The averaged transit time as a function of distance downstream from the initial stopped position of the last car is plotted in Fig. 7 for each of the nine experimental conditions. It can be seen that after both the lead and last cars had reached the final cruising speed, usually within 1000 ft of the starting position, the platoon spread out. Despite very

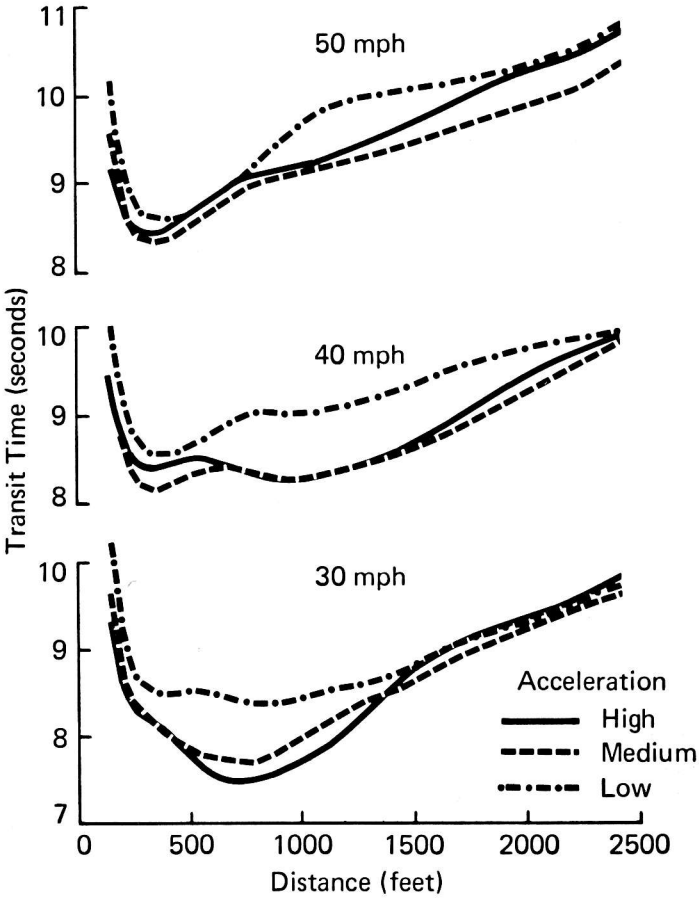

Fig. 7. The transit time of the platoon at varous positions along the roadway is shown versus downstream distance from the initial stopped position of the last car for each of the experimental conditions investigated. Each curve represents the average of all the runs with the same lead car acceleration and speed u_0.

different transit time characteristics immediately downstream from the starting position for runs of different control conditions, the transit times at 2400 ft are almost identical with runs of the same cruising speed. In the early part of the relaxation process, the different configurations reached at the end of the acceleration phase due to different sets of initial conditions were corrected to a near-steady-state condition with moderate adjustments; and then, final adjustments were made by the following cars of the platoon to achieve a steady state with primarily small perturbations of approximately ±5 ft/sec around the cruising speed of the lead car. Since in all the runs the platoon was moving to a steady state by increasing platoon length the average speed of the last car in the relaxation phase was necessarily less than that of the lead car. However, with the small perturbations the difference between the time averaged speeds of the lead and the last car was very small, resulting in a slow drift towards higher transit times as shown in Fig. 7.

At the time the platoon reached the end of the predetermined 0.6 mile roadway section used for these experiments, the data indicates for each run that the platoon was continuing to expand. This suggests that steady states had not yet been achieved in these experiments.

An alternative vantage point for viewing the starting dynamics of vehicular platoons is the flow-concentration diagram. Using the transit time of the platoon at each 50 ft interval on the roadway, the flow, q, vehicles/hour, as measured by an observer at each of these positions is readily calculated. The corresponding concentration, k, vehicles/mile, for each position was estimated by taking the arithmetic average of the length of the platoon at the beginning and end of the transit time.*

Figure 8 illustrates three examples of such calculations. The stopping maneuver has not been included in these graphs. The curves labeled A, B, and C in Fig. 8 are for the following test runs: high acceleration and u_0 = 50 mph; high acceleration and u_0 = 30 mph; and low acceleration and u_0 = 50 mph, respectively. Since each point plotted is for 50 ft increments along the road, these plots graphically display the flow-concentration history for a test run as the platoon moves along the roadway. The case given by curve A illustrates that a quasi steady state is reached. For a considerable period of time the lead and last vehicles are traveling at about the lead car control speed, u_0. However as can be seen from this curve, the platoon slowly expands its length as the q, k point moves along the constant speed line.

The case shown in curve B of Fig. 8 is very typical of the test runs for high acceleration to the low speed of 30 mph. In every case of this group, the q, k graphs indicated an "accordian" type motion of the platoon as reflected by the 'loop'. This motion is mainly caused by the overshoot in speed of the following vehicles. In this case the platoon approaches the steady state from above the

*The reader is cautioned to interpret these calculations of concentration with care since the platoon length during the initial starting phase changes considerably during the transit time of the platoon.

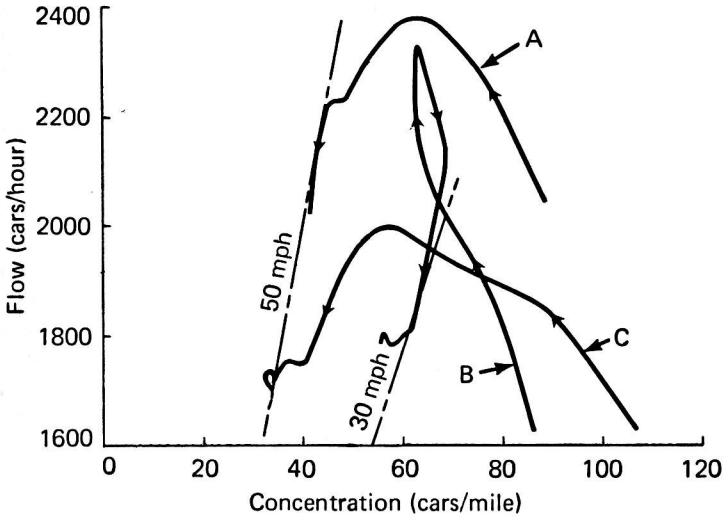

Fig. 8. Platoon flow versus average concentration measured at positions along the roadway for three test runs. Each run shown is a typical case among runs of the same experimental condition. The broken lines are constant speed lines of speed u_0. Curves (*A*), (*B*) and (*C*) are test runs for the following conditions: high acceleration and u_0 = 50 mph; high acceleration and u_0 = 30 mph; and low acceleration and u_0 = 50 mph, respectively.

operating speed, u_0. It also expands slowly with a perturbation near the end. The case given by curve *C* of Fig. 8 is for the same test run whose lead and last car speed histories are exhibited as Case A in Fig. 3. Here the operating speed is just reached before the stopping maneuver of the lead vehicle is executed. A careful comparison of case A in Fig. 3 and curve *C* in Fig. 8 is instructive.

Discussion

This paper has been devoted to a study of the starting characteristics of a platoon composed of six full-size automobiles. The approach taken has been primarily an experimental one and the measurement of the vehicle trajectories of the lead and last vehicles provides a data base from which a number of interesting dynamical features have been determined. Specifically, the characteristics of the starting phase, including the initial acceleration and relaxation phases, have been described in detail. It is noted that this starting phase cannot be so simply described as was the case with bus platoons reported in an earlier work by the authors.[1] It would appear that drivers using automobiles which have a considerably wider range in vehicle performance, make a number of 'corrections' as they accelerate up to speed. This is in contradistinction to the case with bus platoons where it appears that usually only one 'correction' is employed.

The speed at which the starting wave propagates along the roadway has also

been examined in detail. Reasonably consistent results have been obtained for platoon speeds above 30 ft/sec. The most interesting aspect of these results, however, is that for low platoon speeds the data did not fit Eq. (1) which relates the speed of the platoon with the speed of propagation of disturbances. Indeed, it would appear that in any specific test run the speed of propagation of a disturbance is approximately a constant determined by the initial platoon length and the starting delay. Because of the high accuracy of the experimental information and the consistency of this phenomenon, this result sheds possible doubt on the validity of earlier related work.

The study of the transit time of the platoon at points downstream should be useful for the planning of pre-signals and signal funnels of the types described by von Stein[8] and for the location and synchronization of progressive traffic signal systems. For example, Fig. 7 shows that with standard American vehicles and 30 mph cruising speed for the queue leader, there existed a minimum for the transit time at approximately 700 ft downstream measured from the initial stopped position of the last car, or ~130 ft (the platoon length on starting) less if the lead car position is used as the distance origin. If the queue leader has a low acceleration capability, there is a very flat plateau from 400 to 1000 ft in the neighborhood of the transit time minimum for the 30 mph runs. Similar results regarding the location of minimum transit time can also be observed in Fig. 7 for other cases. Since the reciprocal of the transit time is the flow rate of cars in the platoon, the maximum flow that can be established at different locations downstream from a traffic signal can also be estimated from the transit times shown in Fig. 7. This, however, would require assumptions regarding the headway times of the 7th, 8th, 9th, etc., vehicles.

One of the primary limitations of the analysis presented here is that all of the calculations have been based on the trajectory information of the lead and last vehicles. This information on the dynamics of the platoon provides limited knowledge of what is occurring during the starting transient. Most of the results obtained in the present study bring out rather sharply the need to obtain the details of what is happening within the platoon so that driver-to-driver coupling can be better understood.

On the other hand, the information reported in this paper, limited as it is, does demonstrate a number of features of platoon behavior in the starting transient that car-following models to date cannot take into account. This latter point is of particular importance with respect to simulation calculations of urban networks where car-following models are frequently used in simulating the dynamics of vehicular platoons.

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