EFFECTS OF SONIC BOOM ON
AUTOMOBILE-DRIVER BEHAVIOUR

by

Orest Volodymyr Nowakiwsky

June, 1974.
EFFECTS OF SONIC BOOM ON
AUTOMOBILE-DRIVER BEHAVIOUR

by

Orest Volodymyr Nowakiwsky

Submitted May 1974
Acknowledgement

The author wishes to express his sincere thanks to his supervisors, Dr. I. I. Glass and Dr. L. D. Reid, for suggesting the problem and providing the opportunity to conduct this research at UTIAS. Their patience, advice and guidance are gratefully acknowledged.

Special acknowledgement is due Mr. Reinhard Gnoyke, the staff technician, those meticulous work and hundreds of hours of assistance was essential for the preparation and execution of the experiment. His time and technical assistance are very much appreciated.

Thanks are due to Mr. A. Perrin and Mr. J. Unger for their design and construction of the electronic equipment. Mr. B. Leigh's help in developing the delay/trigger circuits is greatly appreciated.

Cooperation received from Mr. E. S. Annis, Director of the University Facilities at York University in providing a location for the test track, as well as the assistance of Mr. D. W. Farren Director of Systems Research at the Ministry of Transportation and Communications in providing one hundred plastic traffic cones for the experiment is acknowledged with thanks.

To the twelve subjects who volunteered their time special thanks are due for their efforts which made the driving experiment possible.

The financial assistance received from The Transportation Development Agency, Ministry of Transport and the National Research Council of Canada is acknowledged with thanks.
Test results are presented on the response and behaviour of automobile drivers subjected to sonic boom disturbances under actual driving conditions. A description is given of the design and development of a portable sonic boom simulator, auxiliary equipment and experimental techniques used to study the nature and severity of the disturbance effects.

The sonic boom simulator, consisting basically of loudspeakers and a function generator was mounted inside a test vehicle. It was able to produce sonic booms that were very similar to what drivers would experience following SST overflights. The simulated booms had overpressures of 3 psf, rise times of about one millisecond and durations of 100 milliseconds.

Two aspects of driving were investigated; the Tracking Maneuver and the Stopping Task. Results from both tests indicated that driver behaviour was not affected by the simulated booms, even though some drivers considered it annoying or disturbing. It may therefore be concluded from present limited statistical tests that current commercial supersonic aircraft under normal flight conditions (without superbooms) would not produce adverse effects on a driver's stopping distance or his ability to follow a particular course.
# Table of Contents

1. INTRODUCTION  
2. BACKGROUND  
3. SONIC BOOM PRESSURE WAVEFORM INSIDE AN AUTOMOBILE  
4. DEVELOPMENT OF A PORTABLE SONIC BOOM SIMULATOR  
5. EXPERIMENTAL PROCEDURE  
6. EQUIPMENT  
   6.1 The Vehicle Track Recording System  
   6.2 The Carrier Oscillator, Amplifier & Course Inductors  
   6.3 Receiving Inductors  
   6.4 Receiver Unit  
   6.5 Test Track  
   6.6 Photo Cells  
   6.7 Time Delay Circuits  
   6.8 Balloon System  
   6.9 Other Equipment  
7. SUBJECTS AND TRAINING  
8. TEST PROCEDURE  
   8.1 Tracking Maneuver  
   8.2 Stopping Task  
9. CONCLUDING REMARKS  
REFERENCES  
APPENDIX A: Statistical Analysis  
APPENDIX B: Questionnaire  
TABLES  
FIGURES
1. INTRODUCTION

The age of the supersonic transport aircraft (SST) has begun. Not only are the prototypes of supersonic transports being tested but the first production models are rolling off the assembly lines. The SST brings with it new technologies and shorter flight times, as well as problems associated with possible pollution of the upper atmosphere and the possible adverse effects of sonic boom on humans, animals and structures at ground level. There is therefore, an urgent need to assess the startle, ecological, and structural effects of the SST in order to provide governments and regulatory bodies with concrete background data that would provide for optimum operating policies for the SST.

Concern has been expressed regarding the possible increase in accident-proneness of automobile drivers subjected to sonic booms. As a result an initial analog study was undertaken by Lips (Ref. 1) at UTIAS concerning the effects of sonic boom disturbances on an individual's compensatory tracking performance for an unstable system, which in certain respects simulated automobile driving. It was found that most individuals were disturbed by the sonic boom and recovered in varying degrees. It is the purpose of this thesis to extend Lips' preliminary investigation by developing a portable sonic boom simulator and experimental techniques to be used in evaluating the nature and severity of a sonic boom disturbance on actual automobile-driver behaviour.

2. BACKGROUND

To answer the question of what, if any effect do sonic booms have on the behaviour of automobile drivers, an extensive literature survey was conducted into the following related fields; physics of the sonic boom, human reactions to sonic booms, simulation techniques for producing sonic booms and behavioural analysis of automobile drivers.

Sonic boom is a phenomenon associated with supersonic flight. It is basically an acoustical disturbance characterized by physical parameters such as overpressure, risetime and duration (Fig. 1). The sonic boom disturbance emanates from an aircraft flying supersonically having a shock wave pattern consisting of two cones generated at the bow and tail of the SST (Fig. 2). The intercept of the trailing cones with the ground produces a horseshoe corridor in which the sonic boom is experienced. By the time the sonic boom disturbance reaches ground level it has coalesced roughly to a pressure waveform having ideally the shape of the letter 'N' (Fig. 3) characterized by a sharp rise in air pressure at the bow wave, a slow drop in pressure to below ambient and a sudden increase in pressure back to ambient pressure at the tail wave. The pressure signature of the sonic boom varies considerably as a result of such diverse influences as ground reflection, aircraft Mach number, altitude, weight, attitude, size and shape, atmospheric variations (winds, temperature, humidity, and turbulence), lateral distance from the flight path, aircraft manoeuvres (turns, acceleration and deceleration) and whether the boom is heard indoors or outdoors. Thus, the sonic boom is influenced by many variables which in turn result in different degrees of reaction from the subjects experiencing the boom. Through field-test observations it has been established that for current commercial supersonic transports under cruise conditions the sonic boom (Fig. 1) would be characterized by overpressures from 2 to 3 psf, risetimes from 0.1 to 10 msec. and durations from 200 to 300 msec (Ref. 2). However, turbulence and manoeuvres can generate superbooms that have overpressures several times greater than these nominal values.
The human response to a sonic boom is exceedingly complex, being simultaneously a physiological, psychological, and sociological reaction. It is influenced not only by the physical stimulus but also by the immediate environment, ambient noise, and various other factors not related directly to the stimulus. The most significant human reaction to the sonic boom is that of startle (Refs. 3,4) and is a function of the risetime and overpressure of the sonic boom (Ref. 5). In general, the shorter the risetime, the greater is the startle reaction, but this again depends upon such factors as age, health, fatigue level, emotional state, and activity at the time of the boom. No direct physical injury can be expected from the sonic boom (Ref. 5). However, it is the startle reaction that presents the greatest threat of injury due to involuntary movements.

Work has already been done by Lips (Ref. 1) on one-dimensional tracking and by Thackray et al (Ref. 6) on two-dimensional tracking tasks. These tasks may be considered to simulate automobile-driving behaviour. The results of these experiments were inconclusive and on the surface seemed contradictory. Thackray suggests that the simulated booms may have elicited more of an orienting or alerting response than a startle reflex" while Lips concluded that "sonic boom disturbances of the type generated by the Concorde SST result in a measurable startle effect" (Ref. 1, pg.12). The discrepancy in the conclusions may be due in part to the difficulty in simulating the sonic boom under controlled experimental condition. According to Thackray, the simulated sonic booms had longer rise times and smaller overpressures than would be expected from an SST. Therefore the booms may have served as an acoustic stimulus rather than a startle trigger, whereas the booms used by Lips did simulate the rise times reasonably well and the overpressures very well.

3. SONIC BOOM PRESSURE WAVEFORM INSIDE AN AUTOMOBILE

The purpose of this project was to study the effects of sonic boom on the behaviour of automobile drivers. For the results to be credible it was decided to simulate driver behaviour using a real vehicle. First, it was necessary to determine what a driver hears inside a vehicle during an SST overflight. This was accomplished by positioning a Ford Pinto sedan inside the horn of the UTIAS sonic boom simulator (Figs. 4,5) and subjecting the vehicle to a range of sonic booms and recording their pressure waveform inside the vehicle. The Ford Pinto was selected for this project since it was the only vehicle that met all of the experimental criteria, requiring the vehicle to:

(a) be able to fit into the sonic boom simulator
(b) be available with an automatic transmission in order to facilitate subject selection
(c) be easily obtainable for rent or lease
(d) be in relatively widespread use by the public.

The automobile was inserted into the simulator and centered along the longitudinal axis of the horn with the front end facing the apex (Fig. 6). The driver's head was thus located at the 70 foot station inside the horn. The total volume of the passenger compartment was estimated to be 65 cubic feet. Two condenser-type microphones were used to monitor the sonic boom pressure signatures. A Bruel and Kjaer (B & K) one inch diameter 4145 microphone and a B & K 2631 pre-amplifier carrier system was located inside the Pinto at the driver's head position. The other microphone, a half-inch diameter B & K 4147 together with a B & K 2631 carrier system was placed outside the vehicle adjacent to the driver's
door and at the same height as the microphone inside the vehicle. The sonic boom signatures detected by the microphones were displayed on a Tektronix 5103 N storage oscilloscope and a Polaroid camera was used to make permanent records of the two pressure waveforms. In all, fifty-four pictures were taken. The car was subject to simulated sonic booms ranging from 2 to 8 psf overpressures and durations from 50 to 300 msec. The automobile interior pressure signatures were recorded for the following cases:

(a) both windows closed
(b) left hand window closed/right hand window open
(c) left hand window open/right hand window closed
(d) both windows open.

These results are presented in Figs. 7 to 15. In each case the upper trace describes the overpressure signature measured at the driver's head position while the lower trace represents the incident sonic boom measured beside the car. The microphones were calibrated using a B & K 4220 pistonphone so that the one inch microphone was exactly four times as sensitive as the half inch microphone. They were adjusted to read:

- one-inch microphone: 1 volt = 1 psf overpressure
- half-inch microphone: 1 volt = 4 psf overpressure

Figure 7(a,b,c) show three particular cases when the calibration of the two microphones was checked before, during and after the experiment respectively. It will be noticed that the upper and lower traces are identical, as they should be. Figure 7b contains lot of 'hash' or superimposed jet noise which results when the fiberglass jet-noise filter was blown out half way through the testing procedure. The filter was repaired and replaced and the tests were concluded.

The sonic booms produced in the horn simulator were not ideal, having longer rise times, and more superimposed jet noise than actual SST booms. Therefore all the results must be viewed within these limitations. In the case where both windows were closed (Figs. 8,9) the interior waveform may generally be described as a damped sinusoidal wave having a longer rise time, and on the average, an overpressure 39% less than that of the exterior sonic boom. For the case where only the right hand window was open (Figs. 10,11) or only the left hand window was open (Figs. 12,13), again longer rise times and damped sinusoidal components are seen in the interior response waveforms. However, the initial overpressures on the average were 35% and 33% greater, respectively, than their corresponding exterior excitation waves. In the case where both windows were open (Figs. 14,15) it is seen that the interior pressure-time history has a very close resemblance with the exterior sonic boom signature, the only exception being that the overpressure is 27% greater inside than outside the car. Finally, in all cases it can be observed that the amount of superimposed jet noise is considerably less inside than outside the vehicle, implying that the car acts as a low pass filter by absorbing the higher frequency components of the jet noise. Also it seems that the passenger compartment together with one open window acts as a Helmholtz resonator. The resonator pressure fluctuation has the appearance of a damped sine wave, persists for a longer period of time, and can have greater amplitudes than the initial excitation wave. The Helmholtz resonator approach was used by Lin (Ref. 7) and Vaidya (Ref. 8) to predict analytically the time history of the sonic boom
pressure wave as it propagates into rooms through open windows. Observations made by Vaidya (Fig. 16) were very similar to the present results, in particular those shown in Fig. 10.

4. DEVELOPMENT OF A PORTABLE SONIC BOOM SIMULATOR

The first of two major problems that had to be overcome in order that the study be performed, involved the development of some portable device to simulate the sonic boom in a moving vehicle. Three alternatives labelled (a) shock tubes, (b) headphones, and (c) speakers were proposed for consideration with respect to:

1. the cost of the equipment involved
2. time required to assemble, debug, and calibrate equipment
3. credibility of the results obtained using that equipment.

The shock tube system would have utilized several shock tube chambers connected to a wooden horn located either on the roof or inside the trunk of the car. Breaking any of the shock tube diaphragms would generate a very short duration sonic boom. A similar system has been developed at LUV Research Center (Ref. 9). This system was rejected due to the uncertain credibility that could be assigned to the results because the booms had microsecond rise times and very short durations in the order of ten milliseconds.

The headphone system would have required the driver to wear a set of headphones which would produce the required sonic boom signal. The feasibility of using headphones was investigated considerably before it was concluded that the problems associated with sealing the headphones in order to reproduce low frequencies, together with the unnatural environment created for the driver, completely outweighed and cancelled the relatively simpler approach that the headphones seemed to offer.

It was finally decided to go ahead with the speaker system, which was in principle similar to the Loudspeaker-Driven Booth Simulator (Ref. 10) in that the passenger compartment of the Pinto had to be made air-tight and loudspeakers were used to produce the required sonic boom waveform.

To mount the speakers inside the car a 1-3/4 inch laminated plywood wall was mounted behind the two front seats (Figs. 17, 18, 19). The top of the wall was attached by stainless steel brackets to the shoulder belt anchor bolts, and the bottom was bolted directly to the chassis of the car. The wall was laminated to increase its rigidity as well as to contain a built-in rear-view plastic window and a one inch wide channel around its perimeter. An inflatable rubber seal made from bicycle inner tubes was installed inside the channel. Therefore, the front passenger compartment could be sealed perfectly from the rest of the vehicle, just by inflating the rubber inner tube until it had expanded into and filled all the gaps and crevices between the wall and the body of the car. With the wall in place the volume of the passenger compartment was estimated to be 50 cubic feet.

To generate a sonic boom, it was decided to use 18-inch-diameter Goodman loudspeakers (Fig. 18), which have a good frequency response ranging from a few cycles per second, where they act as pistons, all the way to up 3000 Hz. Their overall moving diameter is only fifteen inches and under full power they seem to
have a 1/4 inch throw or displacement. Therefore, the maximum pressure change brought about in the passenger compartment due to one of these speakers can be calculated as follows:

speaker diameter, \( D = 15 \) inches

speaker area, \( A = 1.24 \) sq.ft.

The volume \( V \) displaced by the speaker in a 1/4 inch throw would be:

\[
V = 0.03 \text{ cubic feet}
\]

Since we are dealing with small, acoustic disturbances we may assume perfect gas relations and use Boyle's Law: \( (P_1)(V_1) = (P_2)(V_2) \) where

\[
P_1 = 14.7 \text{ psi} = 2117 \text{ psf}
\]
\[
V_1 = 50.00 \text{ cubic feet}
\]
\[
V_2 = V_1 - V = 49.97 \text{ cubic feet}
\]

Therefore \( P_2 = \frac{(P_1)(V_1)}{(V_1 - V)} = 2118 \) psf.

Therefore the change in pressure in the passenger compartment resulting from one speaker displacement should be one psf.

In order to produce overpressures of three psf, four Goodman 18-inch speakers were mounted on the wall (Fig. 18). In this mode the wall acted as an infinite baffle. Each of the four speakers was driven separately by an RCA HC2000 dc amplifier having 100 watts rms maximum power output. Thus the system had a capacity to supply the speakers with a total of 400 watts of electrical power. The simulated sonic boom was triggered by a five segment function generator that produced a voltage signal, which in turn was amplified and fed into the speakers that generated a pressure signature inside the passenger compartment. Both the function generator and the amplifiers required a portable 38 volt dc power supply which consisted of six lead-acid 12 volt motorcycle batteries. It supplied sufficient electrical power for about 200 sonic booms, more than enough for one day of tests and was easily recharged overnight.

Initially it was decided to simulate the type of sonic boom that the driver would hear when his windows were closed. The reason being that the over-pressure and rise time requirements were less severe than in the other cases. The type of waveform we wanted to produce inside the passenger compartment is shown in the upper trace of Fig. 8. The function generator was programmed to produce an exact electronic analogue of this pressure signature. The upper trace in Fig. 20 shows the electronic signal which was played through the speakers, while the lower trace shows the pressure waveform resulting inside the passenger compartment. What we wanted but did not get was a pressure signature similar in shape to that of the electrical signal. The main reason that the pressure did not follow the speaker waveform was due to air leaks in the passenger compartment as seen from the lower trace in Fig. 20, where as certain pressure was reached but could not be maintained. As a result another effort was made to seal the leaks. All the ventilation ducts were sealed off, the heater, fan, and hand brake were removed and the remaining holes in the bulk head were plugged up. The only leaks remaining occurred around the doors and windows and these were minimized to the best of our ability by using silicon sealants. The pressure waveform was repeatedly checked, but the pressure
could not be maintained for the desired length of time.

It was then decided to attempt to simulate the open window case, which had shorter rise times and higher overpressures but did not require holding the pressure at a particular level for any length of time. One conclusion that was drawn from the above exercise was that it would never be possible to obtain a pressure signal similar in shape to the electrical input, since the speakers and the passenger compartment distort the acoustic wave. Therefore, our electrical input had to be predistorted to obtain the required result. A trial and error approach was used (Fig. 21) to obtain a reasonable looking N-wave with an over-pressure of 3 psf, duration of 100 milliseconds and rise time of the order of one millisecond. The signature of the simulated sonic boom that was eventually used in the automobile driving experiment is shown together with its electrical analogue in Figs. 22 and 23. This simulated sonic boom pressure waveform, having 3 psf overpressure, corresponds very closely to what would in fact be observed inside the passenger compartment if the Pinto, with both windows open, was exposed to an external sonic boom with an overpressure of 2.5 psf. This conclusion is based on the results of the tests conducted inside the UTIAS horn simulator indicating that for the case where both windows were open, the interior pressure wave was similar in shape to the exterior pressure signature except that the interior waveform had a 27% greater overpressure. It should also be observed that the duration of the simulated boom is only 100 msec. long, about one-half of the duration expected from a commercial SST. This difference however, does not affect the results that may be obtained when studying human response since work by Robinson and Johnson (Ref. 11) had indicated no variation in subjective loudness with sonic booms of different durations, ranging from 100 to 500 msec.

5. EXPERIMENTAL PROCEDURE

Having developed a portable sonic boom simulator, the second major problem to be overcome was that of developing an experimental procedure which would indicate whether or not sonic booms would make drivers accident-prone. Many studies had been conducted to determine what parameters are involved in a driver's behaviour and his interaction with the vehicle and the road. Block diagrams and mathematical models have been constructed, but the driver-vehicle-highway complex has so many variables, any one of which may dominate at any given instant that the probability of obtaining a high correlation with a single factor or group of factors related to accidents is very remote. Presently there exist no criteria by which a driver, or maneuver can be classified with respect to accident-proneness. It was therefore decided, only to look for visible effects that sonic booms might have on the behaviour of automobile-drivers such as: a momentary loss of control, deviation from a prescribed path or inability to react to an unexpected event. Consequently two aspects of driving were investigated, the tracking maneuver and the stopping task.

Twelve subjects were asked to drive the instrumented Pinto (Fig. 24) on a test track located in a large paved parking lot. The track was 2500 feet long and had both slalom and straight sections defined by plastic pylons and a longitudinal copper cable down the centre. The cable carried a 2000 Hz signal which was detected by solenoid inductors mounted on both sides of the car. The modulated signal from the solenoids was recorded on tape and provided a continuous record of the position of the vehicle with respect to the cable. A photo-electric circuit was set up across one of the straight sections. Breaking the circuit caused two balloons (on random runs) located 150 feet further down the track to inflate rapidly, thus providing the driver with an unexpected or startling event.
The tracking maneuver involved driving along the prescribed course and recording the accuracy achieved by noting the number of plastic cones that had been disturbed as well as recording on tape the vehicle's deviation from the centre-line. The stopping task consisted of measuring the distance required to stop the vehicle when its path was suddenly blocked by rapidly inflated balloons (Fig. 25). During this driving sequence, the subjects were exposed to the simulated sonic booms which were generated inside the vehicle by the four 18 inch loudspeakers and function generator described earlier.

6. EQUIPMENT

The test vehicle used in the driving experiment was a regular 1973 Ford Pinto, 2-door sedan, equipped with a 3-speed automatic transmission, 2300-cc 4 cylinder engine, manual steering, manual brakes (front discs) and an electric rear window defroster. The weight of the vehicle with the instrument package and driver was approximately 3000 lbs. The principle dimensions of the vehicle were:

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall length</td>
<td>169.0 inches</td>
</tr>
<tr>
<td>Overall width</td>
<td>69.4 inches</td>
</tr>
<tr>
<td>Overall height</td>
<td>50.5 inches</td>
</tr>
<tr>
<td>Wheelbase</td>
<td>94.2 inches</td>
</tr>
<tr>
<td>Track: front</td>
<td>55.0 inches</td>
</tr>
<tr>
<td></td>
<td>55.8 inches</td>
</tr>
</tbody>
</table>

With the 'speaker wall' in place and spare tire removed the volumes were:

<table>
<thead>
<tr>
<th>Compartment</th>
<th>Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>Front passenger</td>
<td>50 cubic feet</td>
</tr>
<tr>
<td>Rear passenger</td>
<td>15 cubic feet</td>
</tr>
<tr>
<td>Trunk</td>
<td>7 cubic feet</td>
</tr>
</tbody>
</table>

Since the experiments involved driving an automobile around a track it is best to differentiate between the mobile equipment mounted on and inside the Pinto and the stationary equipment located at the control site. A flow chart of the equipment is shown in Fig.26. All the mobile equipment is shown located below the dotted line in the flow chart. It consisted of: FM antenna, FM radio receiver, function generator, dc amplifier, loudspeakers, solenoids, tracking receiver, FM tape recorder, power supplies and DC-AC inverter. Most of the above equipment was located in the trunk of the Pinto secured by brackets and cushioned with polyurethane foam as shown in Fig. 27.

The FM antenna (model FMX26) consisted of crossed folded dipoles to enable it to receive signals from all directions. It was mounted on the roof of the car using rubber suction cups and secured with nylon guidelines. Its purpose was to receive the trigger signal that would set off the sonic boom in the passenger compartment. The antenna was connected to a small battery powered FM receiver which was tuned to 92.8 MHz, the transmitting frequency. The signal from the receiver was fed into a pulse width noise discriminator which allowed only genuine trigger pulses to activate the function generator. Once activated the five segment function generator produced a predistorted electronic analogue signal of the sonic boom (Fig. 22) which was fed simultaneously into the four channel amplifier and into one of the channels of an Ampex FM tape recorder. This signal was then amplified and played through the four loudspeakers which generated the required sonic boom.
The *Ampex* FM tape recorder had two channels through which simultaneous recordings could be made. One channel was used to record the signal from the function generator thus providing a record of how many and when the booms were heard. The other channel was used to record the vehicle's tracking performance. The power supply for the tape recorder consisted of a 12 volt car battery and a DC-AC inverter providing the 110 VAC 60 Hz required electrical power. The tape recorder used seven-inch reels and Scotch '207' brand magnetic tape. All recordings were made at a speed of 3-3/4" per second, which permitted a maximum of three hours of data to be recorded on one reel of tape.

A 38 volt dc power supply which was made up of six 12 volt motor-cycle batteries supplied the required electrical power to the four channel amplifier, function generator and the vehicle tracking system and was located on the floor in front of the right hand passenger seat in order to maintain a balanced weight distribution.

6.1 The Vehicle Track Recording System

A driver's performance throughout the experiment was measured both in a traditional and novel way. The traditional method consisted of using plastic traffic cones to provide an outline of the course and a record was kept of the number of cones that were disturbed on any particular run. This was fairly crude and detected only large deviations from the set course. The novel method consisted of using an electronic system recently described by Grant (Ref. 12) which detected and continuously recorded the path taken by the vehicle with respect to a fixed cable. The vehicle track recording system shown schematically in Fig. 28 depends on the mutual inductive coupling between the course inductive cable, energized by an audio frequency carrier and two receiving inductors.

The system consisted of an oscillator/amplifier which generated the carrier frequency and a receiver unit to process the signals induced in the receiving inductors. The receiver unit provided a polarized dc signal with the frequency of the vehicle's deviations from the radiating cable. As the centre of the car crossed the cable the polarity of the signal would be reversed. Also the signal amplitude varied as a function of the vehicle's deviation from the cable according to the calibration curve shown in Fig. 30. This system was limited by the inductor spacing to detect a deviation of 36 inches from the centre of the track. At this position one of the inductors would be directly over the cable and the signal amplitude would be in the nonlinear region of the calibration curve. However, since the inductors were separated by six feet and the track width was only ten feet, any deviation from the centre-line of more than two feet would result in hitting the plastic cones which defined the borders of the track. Therefore the function of this system was to monitor the driver's performance within the linear region of the deviation/response curve (Fig.30).

6.2 The Carrier Oscillator, Amplifier & Course Inductor

The oscillator used a Wien bridge circuit tuned to 2000 Hz in a feed back loop of an IC amplifier connected to an RCA HC 1000 power amplifier. The course inductor was the amplifier's load and had a resistance of 1.6 ohms per 1000 feet. The total length of the cable was 2500 feet, thus providing the amplifier with four ohms resistive load.
6.3 Receiving Inductors

These were six-inch long solenoid inductors having 2000 turns of single copper wire around an iron core. They were secured inside two adjustable black plywood boxes located six feet apart on a wooden beam bolted to the chassis of the car just below the front bumper (Fig. 36). The centres of the inductors were eleven inches above the ground. The inductors were also inclined sixteen degrees towards the car in order to be tangent to the circular field being radiated by the wire. Using this arrangement the deviation/response curve was calibrated as shown in Fig. 30.

6.4 Receiver Unit

The schematic diagram of this unit is shown in Fig. 29. It consisted of two identical amplifier and rectifier channels. Each channel received induced signals from its own separate solenoid. The carrier frequency was filtered out using RC-networks leaving only the low frequency tracking signal. This unit was located in the trunk of the car and its output was connected to the second channel of the FM tape recorder.

6.5 Test Track

The track was laid out in parking lot 'F' at York University which was 500 feet long and 250 feet wide and contained no physical obstructions except for a single grass covered median running approximately down its centre. It was oriented roughly in a north/south direction having a gentle downward slope of about one foot per one hundred feet toward the south. The course consisted of three sections; first a 1000 foot large slalom course followed by a 500 foot shallow slalom and then two 500 feet straight sections. The large slalom was composed of seven semi-circular arcs having a 32 ft. radius labelled A, B, C, D, E, F, and G in Fig. 31. The shallow slalom was constructed around a sinusoidal wave with a 6 foot amplitude and 80 foot wavelength and contained eight turns stretching from corners H to J. The centre of the track was defined by a solid THW #12 insulated 'Flameseal' copper wire that was attached to the asphalt surface of the parking lot by 1-1/4 inch concrete nails and ethyl cellulose cable clamps spaced every twelve inches. The track was ten feet wide. Its borders were defined by one hundred 18-inch high orange plastic traffic cones located at strategic positions around the course. The control site was placed near the centre of the straight section of the course running parallel to the edge of the parking lot. Here most of the following stationary equipment was located: photo-cells, counter, trigger-circuit, balloons and transmitter as shown in Fig. 32.

6.6 Photo-Cells

The photo-electric circuits separated by ten feet were positioned across the track at the control site. Each circuit consisted of a light source and photo-cell placed on one side of the track and a one square foot adjustable mirror on the other side, thus avoiding problems with wires crossing the track. The two photo circuits were connected to a 5325A Hewlett Packard universal digital counter which determined the time it took the vehicle to break both circuits. Knowing the time and the separation of the photo-cells, the speed of the vehicle could be calculated. The first photo-cell was also connected to two time delay circuits.
6.7 Time Delay Circuits

Two time delay circuits were developed to provide an accurate and automated method for studying the driver's performance during the stopping task. One circuit delayed for one second the inflation of two balloons located 150 feet from the first photo-electric circuit, after it had been interrupted. The other delay circuit automatically (if desired) triggered a sonic boom within the car at a preselected time with respect to the balloon appearance. The purpose of this arrangement was to study any difference in performance that may have resulted if the driver was boomed prior to, rather than during or after seeing the balloons inflate. By turning a dial, the second delay circuit could be set to trigger a sonic boom with a delay of 0.0, 0.5, 1.0, 1.5, 2.0, and 2.5 seconds after the first photo-electric circuit was broken.

6.8 Balloon System

The purpose of using balloons was to have both a cheap and easily replaceable system that would be able to block suddenly the driver's path and at the same time not damage the vehicle in case of a collision. Latex '7 - 28' balloons were used. They were located 150 feet down the track from the first photo-cell. They were inflated by helium to a height of 28 inches in just 250 msec. by a two stage solenoid valve. Helium, from a high pressure cylinder, was used to obtain a faster inflation rate than was possible with either nitrogen or air, due to its higher speed of sound. It also provided some buoyancy which helped to stabilize the balloons in a vertical position.

6.9 Other Equipment

In addition to the time delay circuits there was also a manual override button which could be used to trigger a boom at any time, anywhere on the test track. The trigger pulse was sent from the control site to the vehicle by an FM transmitter operating at 92.8 MHz. The transmitter, powered by a 12 volt dc supply, had 500 milliwatts of power into its final stage, resulting in the radiation of about 250 milliwatts of power. The only remaining piece of equipment was a stop watch used to clock the driver's time required to complete one lap of the course.

7. SUBJECTS AND TRAINING

Volunteer subjects were selected from the staff and student body at the Institute for Aerospace Studies, University of Toronto, under the provisions regulating the use of volunteers in experiments. The purpose and general procedure was explained, a time and date for the test was selected and a consent form was signed by each of the subjects. In all, twelve volunteers took part in the actual testing. Most were experienced drivers ranging in age from 23 to 38 years. Table 1 provides additional background information about the subjects.

Upon arriving at the test site the subjects were asked to familiarize themselves with the vehicle and track by driving twice around the course at a relaxed speed. They were then instructed about the test procedure.

8. TEST PROCEDURE

The test involved completing four runs followed by a rest period during which a questionnaire (App.B) was answered. The subjects then returned and
completed four more runs. Each run consisted of doing two laps around the course, unless the track was blocked by two inflated balloons, in which case the driver was required to stop the vehicle in as short a distance as possible trying not to hit the balloons. Before each run the drivers were told that they may or may not experience a sonic boom and/or be stopped by balloons. They were also told that their lap time would be monitored and were urged to drive as quickly and carefully around the course as possible while avoiding hitting cones, since each cone disturbed would add a five second penalty to their lap time. They were then asked to check their seat-belts, close their window and to start the run when they heard the trunk close. The test operator, after instructing the driver, checked and turned on the equipment in the trunk noting the position of the recording tape. The trunk was closed and the test run began. A stop watch was activated simultaneously with the start of each run. The operator then reset the counter and preset the automatic time-delay trigger system if the stopping distance was to be studied. If not, the operator would manually trigger the sonic boom on corners F and/or J, depending on the run and observe the number and location of any cones that were disturbed. The driver's lap time was recorded at the end of the first lap. Each run would end after two laps were completed with the vehicle back at the control site. If however, the driver was stopped by balloons, then the stopping distance measured from the tip of the front bumper to the balloons and the vehicle's stopping speed, as determined by the counter, were recorded. The equipment in the trunk was turned off and the driver asked to drive back to the starting position. All drivers were given the same instructions and the test runs were conducted in the same sequence as described below:

Training run with no booms, completed two laps.

Run #1. Stopped with no boom

Run #2. Stopped with boom occurring 0.5 seconds prior to balloon inflation.

Run #3. Boomed on corner F during first lap, and boomed on corner J during second lap.

Run #4. Stopped with boom occurring at time of balloon inflation.

REST PERIOD

Run #5. Boomed on corner J during first lap and stopped with boom occurring 0.5 seconds after balloon inflation.

Run #6. Boomed on corner F during the second lap.

Run #7. Stopped with boom occurring 1.0 seconds after balloon inflation.

Run #8. Stopped with no boom.

8.1 Tracking Manoeuvre

The tracking manoeuver was one aspect of driving behaviour to be studied. Its purpose was to determine whether or not a driver would momentarily lose control or deviate from a prescribed path when subjected to a sonic boom. For this investigation the track was designed to contain two slalom sections and several different corners requiring the subjects' full concentration and complete physical control over the vehicle at all times, in order for the course to be successfully negotiated.
This was to prevent driver conditioning and to eliminate his anticipation of the sonic boom occurrence. In spite of its demanding character the course did simulate actual driving behaviour that might be encountered under conditions that restrict the driver to following a particular path as in fast moving multi-lane heavy traffic or single lane narrow highways. This study involved recording the driver's accuracy in following the course (Figs. 33, 34, 35) by observing the number and location of the plastic cones that had been disturbed as well as recording on tape the vehicle's deviation from the centre-line. Special attention was devoted to both corners F and J where on two separate occasions each driver was subjected to a sonic boom. In this study corners F and J were each negotiated a total of 24 times with booms and 96 times without booms and the following results were observed for all drivers:

Cones were disturbed on 2 occasions when the driver was boomed on corner F.

Cones were disturbed on 1 occasion when the driver was boomed on corner J.

Cones were disturbed on 1 occasion when the driver was not boomed on corner F.

Cones were never disturbed when the driver was not boomed on corner J.

Therefore when drivers were boomed on corners F and J, cones were disturbed in 8% and 4% of the cases respectively. Similarly when drivers were not boomed on corner F and J, cones were disturbed in 1% and 0% of the cases respectively.

The information from the vehicle track recording system confirmed our visual observations. Tracking records of three different runs are shown in Fig. 33. Each record consists of an alphabetically labelled sinusoidal trace representing the driver's performance on the track. The letters identify the vehicle's location and correspond to the corners indicated in Fig. 31. At the bottom of each record is a straight line with one or two vertical marks indicating the time at which the driver was subjected to a sonic boom. Both of these traces were recorded simultaneously on tape and then reproduced by a two channel chart recorder, thus preserving their exact time relation. The horizontal time scale in all records is one second per millimeter; one millimeter being equivalent to one small grid space. The vertical scales differ and are indicated below each tracking record. All traces exhibit a kind of sinusoidal appearance indicating that drivers continuously deviated from the centre of the track as they negotiated the course. According to the calibration curve (Fig. 30) when either the right or left hand receiving inductor was closer to the radiating cable a positive or negative signal was produced respectively. Therefore the tracking records indicate that all drivers had a tendency to take all corners on the outside of the track deviating between 1.5 and 2.0 feet from its centre. Other characteristic shapes appearing in these traces include particularly the small oscillations found superimposed on the peak amplitudes of the larger sinusoidal waveforms as well as the large, very rapid oscillations having a spike appearances. The former waveform resulted when one of the receiving inductors had travelled some distance immediately above or close to the radiating cable. This is observed in Fig. 33(a) on corners A, E, F, G, A, B, and E, as well as in Fig. 33(b) on corners E, G, A, D, G, and K. The other spike waveform resulted when the vehicle completely crossed the cable and the tracking signal was forced into the nonlinear region of the calibration curve (Fig. 30).

Figure 33(a) shows the tracking record of run #6 performed by driver #1.
This run consisted of two laps with a boom occurring on corner F on the second lap. In this run the driver disturbed a cone on corner F on the first lap when there was no boom, but managed to avoid the same cone on the second lap when being subjected to a boom. The track record indicates that his average speed on the large slalom, between corners A and H, was fifteen miles per hour and that on both laps on corner F, he deviated approximately two feet from the centre of the course. Similarly Fig. 33(b) shows the tracking record of driver #6 performing the same run as driver #1 described in Fig. 33(a). Here the vertical scale is different from the previous case, being a factor of 4.4 greater. Again the tracking record indicates that the driver's maximum deviation from the centre of the track on corner F was similar on both laps, but the driver did hit a cone on corner F during his second lap when subjected to a boom. His average speed on the large slalom was 17 miles per hour. Figure 33(c) describes the tracking record of run #3 performed by driver #7. The run consisted of two laps with booms occurring on corner F and J on the first and second lap respectively. The driver's average speed on the large slalom was 19 miles per hour. No cones were disturbed on this run since he deviated only 1.5 to 2.0 feet from the centre of the course. Sonic booms which occurred on corners F and J did not result in any obvious change in his driving performance.

The vehicle tracking recording system was used to provide a continuous record of the path taken by the vehicle with respect to the fixed cable. It was hoped that the output of this system could be compared to the analogue results obtained by Lips (Ref. 1). In his case subjects performed a one-dimensional compensatory tracking task which required them to follow a random function signal by means of keeping an error bar centered on an oscilloscope display unit. The error signal which the subjects had to minimize was equal to the sum of the simulated vehicle dynamics output and the random function input. The sensitivity and stability of this system was varied and subjects' response to sonic booms from the UTIAS horn simulator was studied. Continuous graphic records were made of the input, error, wheel output, sonic boom, and scoring signals. Lips claims that the exposure to sonic boom disturbances resulted in a variety of responses ranging from negligible change in performance to a total loss of control. The more significant response involved an "initial jerk or holding action" occurring less than half a second following the boom, and was called an "initial" startle. Following this a 'normal' or 'classic' startle appeared. This response was characterized by both amplitude and frequency change with respect to pre-boom conditions as shown in Fig. 33(d), and required an average of 15 seconds for subjects to regain normal control over the tracking task. Also the peak amplitude response after the boom was a factor of two greater than the pre-boom amplitude envelope.

The tracking records from our actual driving experiment did not indicate any similar driver response observed by Lips. There was no apparent increase in the amplitude of the vehicle's deviation from the centre of the track, nor any increase in the frequency to correct the tracking error following a boom occurrence. The tracking records did establish conclusively that drivers negotiated the course within the boundaries of the track, maneuvering the vehicle to within inches of the cones. With this in mind the few cases where cones were disturbed during the experiment assume little significance.

The discrepancy between our results and those of Lips may be explained by the fact that his task was mentally intensive while ours was physically intensive. In his case subjects never saw the random signal that they were tracking and only reacted to the tracking error post-factum. This required continuous and intensive concentration as well as anticipation of the random signal. Any
'initial jerk' or 'holding action' that resulted from sonic boom startle would then significantly magnify the tracking error requiring the subjects to increase the amplitude and frequency of their response in order to correct the increased error.

In our real driving experiments drivers had a well defined track to follow which did not require as much mental concentration as it did physical control of the vehicle. The track also provided the driver with several seconds of lead time to prepare for a particular maneuver. Therefore a maneuver during which the boom occurred was not affected since it was already predetermined and only had to be physically executed. Any 'initial jerk' or 'holding action' that may have resulted from the sonic boom startle would be too short to affect the vehicle's position on the course and thus would not require large amplitude or high frequency corrective maneuvers. In addition to lead times, drivers also had real-time, visual, kinesthetic, static, and auditory feedback about the performance of the vehicle, while Lips' subjects had only a visual perception of the tracking error. All of these factors probably contributed to making the vehicle dynamics and driver system less sensitive to a sonic boom than had been indicated by Lips.

Several problems were encountered with the vehicle track recording system. A slow but continuous drop in the power supply voltage had occurred throughout the experiment affecting the recording levels of the tape recorder. This problem was overcome in part by recording calibration pulses before runs began. However the voltage drop did cause the zero or centreline calibration to drift, particularly during runs later in the day. Also the drivers' normal performance on the track resulting in large deviation made it difficult to identify any small perturbations that may have resulted from any 'initial jerk' or 'holding action' that may have been caused by a sonic boom. In general, the vehicle track recording system had provided valuable information about the drivers' normal driving behaviour that would otherwise not have been known. It had also established conclusively that our drivers' performing a real driving task, did not exhibit the type of response observed by Lips.

8.2 Stopping Task

The stopping task was another aspect of driving to be studied. Its purpose was to determine how a sonic boom would affect a driver's performance during an emergency situation, in particular its effect on the stopping distance. This study was conducted on the straight section of the track near the control site involving the photo-cells, counter, delay trigger circuits and balloons. It consisted in measuring the stopping speed and distance of the vehicle when its path was suddenly blocked by rapidly inflated balloons. For our purpose the stopping speed was defined as the speed at which the vehicle was moving when it passed through the photo-cell trigger circuits, one second prior to balloon inflation. The stopping distance was comprised of several different components; namely the distance travelled in one second from the location of the first photo-cell before balloons began to inflate, plus the distance covered during the driver's perception and reaction to the balloons as well as the actual breaking distance. The photo-cell circuit and the inflated balloons were separated by exactly one hundred and fifty feet. For our convenience, during the tests, the stopping distance was determined by measuring the distance between the tip of the front bumper and balloons (Fig. 36). This data was then converted to actual total stopping distances. The driver's normal stopping distance without booms was determined at the beginning and end of the testing sequence. During the test the drivers were subjected to sonic booms
prior to, during and after balloon inflation. The raw data is presented in Table II indicating the different speeds at which drivers were travelling and their corresponding stopping distances. Since the stopping speed at which the drivers were travelling varied from twenty-three to thirty-eight miles per hour it was decided to convert all stopping distances to correspond to a thirty miles per hour stopping speed using a straight line proportional method with a proportionality factor of unity. Table III presents the converted stopping distances for a stopping speed of 30 miles per hour as well as the mean and standard deviation for each case. This data is presented graphically in Fig. 37, where the small circles indicate the average stopping distance and the vertical bars indicate the standard deviation of the data points.

Upon examining this data, it is noticed that the first time drivers were required to stop but were not boomed, their average stopping distance was 131 feet. Next time when they were boomed just prior to being stopped, their distance increased to 132.45 feet. In cases that followed no matter when the boom occurred, the stopping distance improved from case to case with the best average stopping distance being recorded on the last run when no boom occurred. The data points also appear to lie on a curve suggesting that maybe a learning process had taken place from case to case with drivers acquiring or developing better stopping skills. Alternatively, the results may be interpreted to imply increasing driver anticipation of being stopped on successive runs, thus reducing his reaction time which in turn reduced the stopping distance. Most probably, elements of both learning and anticipation were involved in shaping the outcome of the results. The hypothesis that there was essentially no difference between the first two and the last two stopping cases was tested at a 1% level of significance using the Student's t Test (Appendix A). The results indicated that there was no statistically significant difference in the stopping distances between the first two and last two cases. However, when the tests of the same hypothesis was applied to the first and last case when no boom occurred, the hypothesis was rejected, indicating statistically that it is very unlikely that the first and last case belong to the same distribution. But, both of these cases were conducted under the same conditions, except that one occurred first and the other last in the testing sequence. Therefore the 't' test would seem to support the above assertion that some process other than sonic booms was involved in shaping the outcome of the results. However, if sonic booms did adversely affect driver behaviour, then a noticeable anomaly would be observed in the results. Since the spread between the best and worst average stopping distances was only 15 feet and the standard deviation in each case overlapped each other, it is difficult to attach special significance to any particular case.

9. CONCLUDING REMARKS

The sonic boom pressure waveform inside an automobile was investigated. A portable sonic boom simulator together with other equipment necessary to monitor driver behaviour was designed and developed. Two aspects of driving were studied. Both the Tracking Manoeuvre and Stopping Task indicated that driver behaviour was not affected by the simulated sonic booms with 1 msec rise times and 3 psf overpressures. Therefore on the basis of the limited statistical results obtained, it may be concluded that present commercial supersonic aircraft under normal flight conditions (without superbooms) would not have adverse effects on a driver's stopping distance or his ability to follow a particular course. This conclusion may not be surprising in view of the fact that drivers are subjected to far greater
startling conditions during a thunderstorm when overpressures from thunder-type sonic boom and its consequent startle effects may be manyfold greater than those used during the present experiments. There does not appear to be much evidence in the literature that severe thunder booms have led to automobile accidents*

* Inquiries regarding accidents resulting from thunder were addressed to the Collision Data Centre in the Ministry of Transportation in Ontario and Quebec as well as the Department of Motor Vehicles in Albany, New York. In each case there were no data available to indicate any direct cause-and-effect relation between thunder and automobile accidents.
REFERENCES

Rigaud, P. Franke, R. Evcard, G.

Van Houten, J. J.
The purpose of this Appendix is to provide a quick reference to the relevant details of statistical decision theory that was used to evaluate the data from the stopping task. Procedures which enable us to decide whether to accept or reject hypotheses or to determine whether observed samples differ significantly, either from other samples or from expected results, are called tests of hypotheses or test of significance. In testing a given hypothesis, the maximum probability with which we would be willing to risk rejecting a hypothesis when it should be accepted is called the level of significance of the test. In practice, a level of significance of 0.05 or 0.01 is customary, although other values are used. If for example a 0.01 or 1% level of significance is chosen in testing a hypothesis, then there is one chance in one hundred that we would reject the hypothesis when it should be accepted, i.e., we are about 99% confident that the hypothesis is correct.

Since our sample size was small, we must employ the Student’s t distribution in testing any of our results. Upon examining the average stopping distances for the different cases shown in Fig. 37, it was decided to test the following hypothesis that there is essentially no difference in the mean stopping distance between the cases. Under this hypothesis:

\[ t = \frac{X_1 - X_2}{\sqrt{\frac{S_1^2}{N_1} + \frac{S_2^2}{N_2}}} \]

where \( t \) is the Student’s distribution with \( N_1 + N_2 - 2 \) degrees of freedom.

\( X_1, X_2 \) are the sample mean values of case 1 and 2 respectively.

\( S_1, S_2 \) are the sample standard deviations of case 1 and 2 respectively.

\( N_1, N_2 \) are the sample size of case 1 and 2 respectively.

\( \sigma \) is the population standard deviation.

If we apply the above hypothesis to the first two stopping cases we have:

\[
\begin{align*}
X_1 &= 131.0 & S_1 &= 5.7 & N_1 &= 12 \\
X_2 &= 132.5 & S_2 &= 6.6 & N_2 &= 11
\end{align*}
\]

therefore \( t = -0.559 \)

Since this case has 21 degrees of freedom, then on the basis of the two tailed test at a 0.01 level of significance we would reject the hypothesis if the value of ’t’ was outside the range of -2.83 to 2.83. Since the ’t’ value was within the required range, the hypothesis was not rejected and we may conclude that there is essentially no significant difference between the stopping distances of the first two cases. Similar calculations were performed for other cases and the results presented in the thesis.
APPENDIX B: QUESTIONNAIRE

The purpose of the questionnaire was to provide additional information which would help in the interpretation of the test results. Five questions were asked and the replies to them are given below.

1. Rate the effect of the sonic boom as: (a) very startling; (b) quite startling; (c) startling; (d) mildly startling; (e) not startling.

8% rated the effect of the sonic boom as startling.
50% rated the effect of the sonic boom as mildly startling.
42% rated the effect of the sonic boom as not startling.

2. Were the booms more startling in some situations than in others?

33% answered YES
67% answered NO

The following comments were also made:

The boom caused confusion during the sequence when the balloons came up. My reaction to brake for the balloons was delayed.

Depends on the severity of the situation and the number of prior exposure.

YES, when recovering from a turn.

Turning a sharp corner, the booms had the most startling effect.

No, since they were expected.

3. Did the booms affect your driving performance?

42% answered YES
58% answered NO

The following comments were made:

Yes, only in complex situations

Yes, during a spin, a boom is somewhat disconcerting.

Yes, caused nervousness and hence missed part of the track in a lap.

Affected stopping before balloons were inflated. Wanted to brake when I heard the boom.

For the instant when the boom happens it tends to distract one's concentration away from setting up the proper drift for the next corner.

4. In your opinion, would sonic booms affect your driving performance under actual driving conditions?
42% answered YES
58% answered NO

The following comments were made:

Yes, probably only under stress situations or on long uncomplicated driving.

No, it might wake me up.

Yes, if I'd never heard a boom before and was in a trouble situation.

No, traffic noise masks some of the peak and background level and could no doubt dull the senses as well. Other cars are easier to guide by especially when they are moving.

I would think it might depend on one's present mental state, i.e., if one was upset over something else, a sonic boom may aggravate an already tense situation.

This is an artificial situation demanding full concentration, which means it would take an enormous disturbance to distract me.

Yes, since they would happen unexpectedly, my first reaction would be what part of the car fell off, and it would tend to be somewhat disturbing.

No, not very loud.

Yes, in a way, while doing this test, I knew I was going to receive a boom, and was subconsciously awaiting it. In actual conditions, the absence of this "subconscious preparedness" will increase the startle effect.

5. How well does a course simulate actual difficult driving situations (e.g., avoiding an accident, emergency stopping, etc)?

Quite well, although cornering, etc., is expected and so easier and the emergency stop does not require constant vigilance because of only one point possible. However, except for anticipation, quite good.

Concentration required here is probably greater than in actual case. You must keep it up longer here.

Quite well, except that there is no need to avoid other moving traffic in your lane as well as in turns, etc.

Maybe the driver is concentrating continuously for too long. In actual driving, moments of severe concentration occur only intermittently.
The emergency stopping is good and very realistic. The turns are very sharp and under realistic conditions (normal speeds), would probably be impossible to negotiate.

Course is difficult to see. A solid line would be easier to follow.

Not at all. In actual driving other considerations have to be made. You are usually restricted to swerving to the right side, for example.

Very well indeed.
### TABLE I

**DRIVER BACKGROUND DATA**

<table>
<thead>
<tr>
<th>DRIVER NO</th>
<th>AGE (YEARS)</th>
<th>SEX</th>
<th>OCCUPATION</th>
<th>DRIVING EXPERIENCE (YEARS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>38</td>
<td>M</td>
<td>Technician</td>
<td>22</td>
</tr>
<tr>
<td>2</td>
<td>32</td>
<td>M</td>
<td>Research Eng.</td>
<td>16</td>
</tr>
<tr>
<td>3</td>
<td>23</td>
<td>M</td>
<td>Student</td>
<td>6</td>
</tr>
<tr>
<td>4</td>
<td>23</td>
<td>M</td>
<td>Student</td>
<td>3</td>
</tr>
<tr>
<td>5</td>
<td>25</td>
<td>F</td>
<td>Library Tech.</td>
<td>7</td>
</tr>
<tr>
<td>6</td>
<td>24</td>
<td>M</td>
<td>Student</td>
<td>7</td>
</tr>
<tr>
<td>7</td>
<td>27</td>
<td>M</td>
<td>Student</td>
<td>11</td>
</tr>
<tr>
<td>8</td>
<td>33</td>
<td>M</td>
<td>Programmer</td>
<td>16</td>
</tr>
<tr>
<td>9</td>
<td>30</td>
<td>M</td>
<td>Engineer</td>
<td>14</td>
</tr>
<tr>
<td>10</td>
<td>23</td>
<td>M</td>
<td>Student</td>
<td>7</td>
</tr>
<tr>
<td>11</td>
<td>26</td>
<td>M</td>
<td>Student</td>
<td>5</td>
</tr>
<tr>
<td>12</td>
<td>32</td>
<td>M</td>
<td>Research Eng.</td>
<td>10</td>
</tr>
</tbody>
</table>

F - Female, M - Male

### TABLE II

**STOPPING DISTANCE AND STOPPING SPEED**

<table>
<thead>
<tr>
<th>DRIVER NO</th>
<th>NO BOOM</th>
<th>TIME OF BOOM OCCURRANCE IN SECONDS WITH RESPECT TO BALLOON INFLATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>114</td>
<td>24.4</td>
</tr>
<tr>
<td>2</td>
<td>144</td>
<td>35.9</td>
</tr>
<tr>
<td>3</td>
<td>150</td>
<td>35.9</td>
</tr>
<tr>
<td>4</td>
<td>135</td>
<td>29.6</td>
</tr>
<tr>
<td>5</td>
<td>103</td>
<td>23.5</td>
</tr>
<tr>
<td>6</td>
<td>148</td>
<td>32.5</td>
</tr>
<tr>
<td>7</td>
<td>166</td>
<td>37.9</td>
</tr>
<tr>
<td>8</td>
<td>130</td>
<td>31.0</td>
</tr>
<tr>
<td>9</td>
<td>158</td>
<td>35.9</td>
</tr>
<tr>
<td>10</td>
<td>150</td>
<td>35.9</td>
</tr>
<tr>
<td>11</td>
<td>137</td>
<td>31.0</td>
</tr>
<tr>
<td>12</td>
<td>138</td>
<td>31.0</td>
</tr>
</tbody>
</table>

Stop. Dist. - Stopping Distance in feet.
Stop. Spd. - Stopping Speed in miles per hour.
### Table III

**CONVERTED STOPPING DISTANCES FOR A STOPPING SPEED OF 30 MPH**

<table>
<thead>
<tr>
<th>DRIVER</th>
<th>NO BOOM</th>
<th>TIME OF BOOM OCCURANCE IN SECONDS WITH RESPECT TO BALLOON INFLATION</th>
<th>NO BOOM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>STOPPING DISTANCE</td>
<td>STOPPING DISTANCE</td>
<td>STOPPING DISTANCE</td>
</tr>
<tr>
<td>1</td>
<td>140</td>
<td>141</td>
<td>140</td>
</tr>
<tr>
<td>2</td>
<td>120</td>
<td>124</td>
<td>118</td>
</tr>
<tr>
<td>3</td>
<td>125</td>
<td>129</td>
<td>141</td>
</tr>
<tr>
<td>4</td>
<td>137</td>
<td>142</td>
<td>160</td>
</tr>
<tr>
<td>5</td>
<td>131</td>
<td>121</td>
<td>117</td>
</tr>
<tr>
<td>6</td>
<td>137</td>
<td>134</td>
<td>115</td>
</tr>
<tr>
<td>7</td>
<td>132</td>
<td>113</td>
<td>112</td>
</tr>
<tr>
<td>8</td>
<td>126</td>
<td>134</td>
<td>124</td>
</tr>
<tr>
<td>9</td>
<td>132</td>
<td>137</td>
<td>132</td>
</tr>
<tr>
<td>10</td>
<td>125</td>
<td>127</td>
<td>123</td>
</tr>
<tr>
<td>11</td>
<td>133</td>
<td>130</td>
<td>129</td>
</tr>
<tr>
<td>12</td>
<td>134</td>
<td>139</td>
<td>132</td>
</tr>
<tr>
<td>MEAN STOPPING DISTANCE</td>
<td>131.0</td>
<td>132.5</td>
<td>127.8</td>
</tr>
<tr>
<td>STANDARD DEVIATION</td>
<td>5.7</td>
<td>6.6</td>
<td>12.5</td>
</tr>
</tbody>
</table>

STOPPING DISTANCE is expressed in feet.

* This stopping distance was excluded from the calculations of the mean and standard deviation since it started to rain during that particular run. The wet pavement resulted in a greatly increased stopping distance which was not comparable with the other results.
Figure 1. Ideal and real sonic-booms. Reproduced from Ref. 5.
Figure 2. Conical shock wave pattern and resulting overpressure footprint on the ground from a supersonic aircraft. Courtesy of J. J. Gottlieb.
Figure 3: Shock pattern & ground pressure distribution for an aircraft flying at supersonic speed (Ref. 1)
Figure 4. Plan view of the UTIAS Horn-Type Sonic-Boom Simulator. Reproduced from Ref. 1.
Figure 5. The control room layout of the UTIAS Horn-Type Sonic-Boom Simulator. Reproduced from Ref. 5.
Figure 6. The Pinto located inside the horn of the UTIAS sonic boom simulator during tests of the sonic boom pressure waveforms.
Figure 7(a)
Scale:  Hor. 50 msec / div.
Vert. 2 psf / div.
Microphone calibration before tests began.

Figure 7(b)
Scale:  Hor. 100 msec / div.
Vert. 2 psf / div.
Microphone calibration during experiment when the acoustic jet-noise filter was blown out.

Figure 7(c)
Scale:  Hor. 50 msec / div.
Vert. 2 psf / div.
Microphone calibration after tests were completed.
Upper traces: Overpressure signatures measured at the driver's head position when all the windows were closed.

Lower traces: Incident sonic boom measured beside the vehicle.
Figure 9. Upper traces: Overpressure signatures measured at the driver's head position when all the windows were closed.

Lower traces: Incident sonic boom measured beside the vehicle.
Figure 10. Upper traces: Overpressure signatures measured at the driver's head position when only the right hand window was open.
Lower traces: Incident sonic boom measured beside the vehicle.
Figure 11. Upper traces: Overpressure signatures measured at the driver's head position when only the right hand window was open.

Lower traces: Incident sonic boom measured beside the vehicle.
Figure 12. Upper traces: Overpressure signatures measured at the driver's head position when only the left hand window was open.
Lower traces: Incident sonic boom measured beside the vehicle.
Figure 13. Upper traces: Overpressure signatures measured at the driver's head position when only the left hand window was open.
Lower traces: Incident sonic boom measured beside the vehicle.
Figure 14. Upper traces: Overpressure signatures measured at the driver's head position when both windows were open.

Lower traces: Incident sonic boom measured beside the vehicle.
Figure 15. Upper traces: Overpressure signatures measured at the driver's head position when both windows were open.

Lower traces: Incident sonic boom measured beside the vehicle.
Figure 16. Pressure signatures (reproduced from ref. 8) observed by P.G. Vaidya outside (top trace) and at the center of the experimental Westcott room (bottom trace). Vertical scale 0.25 V per div; time base 50 msec per division.
Figure 17. Front view of wall before it was installed inside the car. Black burlap covered surface to protect loudspeakers.

Figure 18. Rear view of wall with loudspeakers in place. Index finger indicates the inflatable seal.
Figure 19.

The front view of the wall inside the Pinto. Top; the inflatable rubber seal is being inflated.
Figure 20. Upper trace: Amplified electrical signal from the function generator that was played through the speakers.

Lower trace: Resulting pressure waveform inside the passenger compartment, measured at the driver's head position.

Figure 21. Trial and error approach used to determine the required predistorted electrical signal.

Upper trace: Pressure waveforms measured at the driver's head position.

Lower trace: Different electrical inputs to the speakers.
Figure 22. Upper trace: Pressure waveform generated by loudspeakers inside the Pinto and used to simulate sonic booms in the driver behaviour experiment. Lower trace: Predistorted electrical signal that was played through the loudspeakers.

Figure 23. Simulated sonic boom pressure signature used in the driver behaviour experiment.
Figure 24. (top)

Instrumented Pinto parked in the starting position at the control site. The receiving inductors mounted below the front bumper, FM antenna, the track cable, the photo-electric circuits (black boxes) and the control panel are all visible.

Figure 25. (side)

The stopping distance is measured from the inflated balloons to the tip of the front bumper.
Figure 26. Equipment Flow Chart

Photo-Cell #1

Photo-Cell #2

0.0 sec variable time-delay circuit

1.0 sec time-delay and trigger circuit

Automatic Manual

High pressure solinoid valve

TRIGGER

Balloons

FM Transmitter

Oscillator

Power Supply

Amplifier

Cable

FM Antenna

12 V dc Battery Power Supply

FM Receiver

DC-AC Inverter

Function Generator

Tape Recorder

Tracking Receiver

Loudspeakers

38 V dc Battery Power Supply

Inductors / Solinoids

Power Supply
Figure 27. Mobile equipment located in the trunk of the Pinto. From left to right; (back row), four channel dc amplifier, tracking receiver, function generator, (front row), 12 V dc battery, DC-AC inverter, FM tape recorder, FM radio receiver.
Figure 28. Vehicle track recording system. The transmission inductor is the copper cable that was laid along the center of the course.
Figure 29. Schematic diagram of the receiver unit.
Figure 30. Calibration curve of the tracking signal as a function of the horizontal deviation from the center of the track.
Figure 31. Schematic diagram of the test track.
Figure 32. Equipment located at the control site. From top to bottom; 38 V dc power supply, stop watch, FM transmitter, time-delay circuit and trigger panel containing two dials for setting delays, two on/off switches for automatically triggering balloons and booms and a manual sonic boom trigger button. Below is a 12 V dc power supply for the lights used in the photo-cell circuit. The Hewlett Packard counter/timer is in the middle. The bottom panel contains the oscillator/amplifier which energised the tracking cable. A 38 V dc power supply and photo-cell circuits are located in the bottom right hand corner.
Figure 33(a). Tracking record of run # 6, performed by driver # 1. One cone was disturbed on corner F during the first lap when no boom occurred. Scale: Hor. 1 sec/mm; Vert. 3.5 ft/cm.

Figure 33(b). Tracking record of run # 6, performed by driver # 6. One cone was disturbed on corner F during the second lap when a boom occurred. Scale: Hor. 1 sec/mm; Vert. 0.8 ft/cm.

Figure 33(c). Tracking record of run # 3, performed by driver # 7. No cones were disturbed. Booms occurred on corners F and J on the first and second lap respectively. Scale: Hor. 1 sec/mm; Vert. 0.8 ft/cm.
Subject I - Unstable system $\beta = 2.25$
- 0.05" RMS input
- Score = 1.53" display

FIGURE 33 (d)  REPEATED SONIC-BOOM DISTURBANCES WITHOUT FULL RECOVERY
Figure 34. The Pinto located between corners B and C, is performing the tracking manoeuvre on the large slalom part of the course.
Figure 35. The Pinto is negotiating the fourth corner of the shallow slalom during the tracking manoeuvre.

Figure 36. The Pinto is being stopped by rapidly inflated balloons. Note the black skid marks from previous runs.
Figure 37. Stopping task results. Circles and vertical bars indicate the average stopping distances and standard deviations respectively for each of the cases.
Test results are presented on the response and behaviour of automobile drivers subjected to sonic boom disturbances under actual driving conditions. A description is given of the design and development of a portable sonic boom simulator, auxiliary equipment and experimental techniques used to study the nature and severity of the disturbance effects. The sonic boom simulator consisting basically of loudspeakers and a function generator was mounted inside a test vehicle. It was able to produce sonic booms that were very similar to what drivers would experience following SST overflights. The simulated booms had overpressures of 3 psf, rise times of about one millisecond and durations of 100 milliseconds. Two aspects of driving were investigated; the Tracking Maneuver and the Stopping Task. Results from both tests indicated that driver behavior was not affected by the simulated booms, even though some drivers considered it annoying or disturbing. It may therefore be concluded from present limited statistical tests that current commercial supersonic aircraft under normal flight conditions (without superbooms) would not produce adverse effects on a driver's stopping distance or his ability to follow a particular course.

Available copies of this report are limited. Return this card to UTIAS, if you require a copy.