Monitoring of Personal Driving Habits and Vehicle Activity

Final Report

Contract No. A132-175

Prepared for:

California Air Resources Board
Research Division
2020 L Street
Sacramento, California 95814

Prepared by

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ABSTRACT

One important tool used by the California Air Resources Board (CARB) in planning and assessing new motor vehicle regulations is the California motor vehicle emissions inventory model. The emissions factors used to estimate the emissions inventory are obtained from laboratory testing of a subset of the on-road fleet. The vehicle activity data, however, are derived from widely dissimilar databases. An improvement in the motor vehicle emissions inventory can be realized by directly linking the laboratory measured emissions of vehicles to how those same vehicles are driven in the real world.

Seven late model vehicles were each equipped with a datalogging device to monitor their actual on-road usage. These vehicles were selected based on their high sales volume in California and were representative of current and projected future emissions control technologies. The vehicles were loaned to participants of CARB's In-Use Light Duty Vehicle Surveillance Project Series-12 for at least 7 days each. Data from approximately 5000 valid trip files were obtained. A trip database was created from statistical analysis of the collected data with the objective of improving CARB's capability for on-road motor vehicle emission inventory modeling.

Data analysis showed that the average trip was 7.6 miles in length. The average trip lasted 13.6 minutes and 31% of all trips were one mile or less. About 40% of all starts were cold starts and 9% of all soak times were more than 1 day. The vehicles were driven an average of 49 miles per day and 7.2 trips per day were taken on average. The time spent in cruise, acceleration, and deceleration modes varied from participant to participant. Seven significant mode transitions were identified: Idle to Acceleration, Cruise to Acceleration, Cruise to Deceleration, Acceleration to Cruise, Acceleration to Deceleration, Deceleration to Idle, and Deceleration to Cruise were identified. Heavy acceleration represented 1.3% of all vehicle operation and 4.6% of all acceleration modes. Findings in this study deviate from current estimates used in the motor vehicle emissions inventory model.

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INTRODUCTION

The South Coast Air Basin, encompassing the Los Angeles metropolitan area, continues to have poor air quality despite the intensive efforts of the California Air Resources Board (CARB) and other regulatory agencies. The ozone level in the South Coast Air Basin still frequently exceeds the Federal standard. Meeting this standard will require increasingly stringent regulation of motor vehicles—the major contributor of air pollutants.

One important tool used by CARB in planning and assessing new motor vehicle emission control strategies is EMFAC, California's motor vehicle emissions inventory model. An accurate model prediction is dependent upon the quality of the emissions inventory estimate. Collection of data from mobile sources poses several problems. Emissions from mobile sources are unsteady and often dependent upon parameters such as vehicle temperature, ambient temperature, vehicle maintenance, driving cycle, trip length, gradient, and load factor.

The vehicle emissions data currently used in California emission models were obtained through the laboratory testing of a subset of the in-use motor vehicle fleet. The vehicle activity data, however, were derived from widely dissimilar databases and transportation models using public survey information which are suspected to lack accuracy and not account for trips less than a mile in length. In addition, real-world acceleration and deceleration rates, as well as peak and average speeds, are often higher than those represented within the Federal Test Procedure (FTP). To improve California's vehicle activity database, other methods for gathering vehicle usage data are required. The installation of datalogging devices into representative vehicles to monitor their actual on-road usage over a specified period is one of these methods. By linking the emissions of vehicles with specific information on how they are driven, an improvement in the emissions inventory could be realized.

SUMMARY

The objective of this project was to collect data on personal driving habits and vehicle activity in order to improve CARB's capability for on-road motor vehicle emission inventory modeling. A trip database was created from statistical analysis of the collected data. The goal was to link this database of on-road vehicle activity with the database of laboratory measured vehicle emissions in order to improve the emissions inventory estimate.

Findings from data analysis of all vehicles were:

- The average of trips taken per day was 7.2 trips.
- Mondays had the lowest average number of trips with 6.5 trips per day.
- Saturdays had the highest average number of trips with 7.8 trips per day.
- The average trip length for all days was 7.6 miles.
- The average miles driven per day was 49 miles.
- Saturday had the highest average miles per day driven with 56 miles.
- Sunday had the lowest average miles per day driven with 40 miles.
- 31% of all trips were less than one mile in length.
- The average trip took 13.6 minutes.
- Of all start events, 40% were cold starts.
- 31% of all soak times were less than 10 minutes.
- 8.9% of all soak times were more than 1 day.
- The average vehicle speed for all participants was 33 mph.
- Heavy acceleration (> 5.5 mph/sec) represented 1.3% of all vehicle operation and 4.6% of all acceleration mode.
- Peak usage time was at 1 pm and minimum usage time was at 11 pm.

CONCLUSIONS

The findings in this study deviate enough from current estimates used in the mobile source inventory model to justify reviewing these estimates. The current on-road mobile source inventory modeling estimate of 60.4% cold starts is significantly higher than this program's finding of 40%. Adjusting the value used in the model would lower the emissions estimate. However, the large percentage of trips (31%) which were less than one mile in length may contribute additional emissions which may partially offset this reduction. The increased number of trips and average miles per day (7.2 trips and 49 miles in this study compared to the current estimate of 3.75 trips and 30.65 miles) was also substantial. Accounting for these factors will also change the emissions estimates.

RECOMMENDATIONS

Because of the significant number of short trips identified in this study, an attempt should be made to assign specific situations (i.e., moving cars in the driveway, driving down the street, etc.) to these trips. Additional studies should be made, perhaps using vehicles equipped with portable gas analyzers, to determine the effects on emissions of these short trips.

Although it appears valid for an "average" trip, the cold start definition of a greater than one hour soak is too simplistic to cover all vehicle driving situations. A start after less than one hour's soak following a short trip maybe more appropriately categorized as "cold" rather than "hot." Using the data collected in this study, it is possible to develop a more accurate definition incorporating other parameters such as engine coolant, catalyst, and ambient temperatures. It is possible with the ATDS datalogger to use time aligned catalyst inlet and midbed temperatures to analyze the time from vehicle start to exothermic condition. This can arguably be used to predict a subjective time to light-off of the catalyst system.

Findings in this study deviated from current vehicles activity estimates used in the motor vehicle emissions inventory model. More specifically, the estimates of the percentage of cold starts, number of trips per day, number of miles per day, and soak time distribution, should be reviewed for incorporation into the model.

PROCEDURES & DISCUSSION

Test Vehicles

Seven vehicles were selected through a screening process involving CARB staff. Features required for selection included:

- ❑ High California sales volume (all vehicles ranked within the top 12 in national sales based upon Automotive News vehicle production data for the 1991-1992 model years).
- ❑ California emissions certified.
- ❑ Representative of current and projected future control technologies.
- ❑ Accessibility for datalogger and instrument installation.
- ❑ Availability of manufacturer support and documentation.

The vehicles selected are listed in Table 1.

Each vehicle was inspected to ensure conformity to the intended specifications. The locations of vehicle transducers and wire looms were identified. Additional onboard computer wiring harnesses for the datalogger were installed as necessary to acquire signals from the onboard ECM and transducers. Air/Fuel Ratio sensors and thermocouples were installed in the appropriate locations.

The following is a list of signals monitored:

- ❑ Vehicle Speed
- ❑ Engine Speed
- ❑ Throttle Position
- ❑ Engine Coolant Temperature
- ❑ Manifold Absolute Pressure or Mass Air Flow
- ❑ Air/Fuel Ratio
- ❑ Oxygen Sensor
- ❑ Catalyst Inlet Temperature
- ❑ Catalyst Midbed #1 Temperature
- ❑ Catalyst Midbed #2 Temperature
- ❑ Catalyst Outlet Temperature
- ❑ Ambient Temperature

Table 1: Test Vehicles

Vehicle/VIN/Engine Family #	Ending Odometer	Engine Configuration	Transmission Type	Body Style	Tire Size
1992 Ford Taurus 1FACP52UXNG235886 NFM3.0V5FXD4	37866	Multiport Injection V-6	3-speed automatic	4-door sedan	P205/70R14
1992 Ford Tempo 1FAPP36X5NK218582 NFM2.3V5FW	23116	Multiport Injection Inline-4	3-speed automatic	4-door sedan	P185/70R14
1992 Chevrolet Lumina 2G1WL54T1N1132451 N1G3.1W8XGZ1	33100	Multiport Injection V-6	4-speed automatic	4-door sedan	P195/75R14
1992 Chevrolet Astro Van 1GNDM19Z2NB125808 N364.3TBTAA3	48232	Throttlebody Injection V-6	4-speed automatic	passenger van	P215/75R15
1992 Pontiac Grand Am 1G2NE5431NM042660 N2G2.3V8XRM9	47399	Mutliport Injection Inline-4	3-speed automatic	4-door sedan	P185/75R14
1992 Honda Accord JHMCB7657NC050577 NHN2.2V5FPC3	34536	Multiport Injection Inline-4	4-speed automatic	4-door sedan	P185/75R14
1991 Toyota Camry 4T15V24EZMU436127 MT42.0V5FCC3	44576	Multiport Injection Inline-4	3-speed automatic	4-door sedan	P185/70R14

The ATDS Datalogger System

ATDS has developed a very powerful and flexible PC based datalogger designed specifically for automotive use. The system used for this project was the original production release version. The ATDS Datalogger has at its core an IBM type AT computer in which the internal computer Basic Input and Output System (BIOS), the Disk Operating System (DOS), the computer power supply, and the basic disk operations have been extensively modified to provide the optimal automotive interface capability without sacrificing system capacity or operating speed.

The ATDS Datalogger is powered directly from the vehicle's 12 volt DC power system. This eliminates the requirement for any external power inverters. Its sixteen (16) data input channels were set up for six (6) K-type thermocouple channels and the remaining ten (10) input channels were vehicle specific as either an analog voltage signal or a frequency signal. For this project, data was recorded at a 2 Hz sampling rate. (The available sampling range was from 100 Hz down to once an hour.) Additional specifications are listed in Table 2.

Table 2: ATDS Datalogger Specifications

Data Capacity:	80 Megabytes
Sample Rate:	0.1 Hz to 100 Hz, 2 Hz for this program
Input Channels:	Standard - 16, Optional - 32, 16 channels for this program
Retrieval Mechanism:	Standard - Diskette, Optional - RS232
Weight:	30 lbs. (13.6 kg)
Power Requirement:	Standard - 12 VDC, Optional - 120 VAC
Operating Temperature Range:	-10° F to 150° F

All seven test vehicles employed the ATDS standard for Datalogger turn-on and record operations. When the driver's side door was opened, the datalogger recognized this as the turn-on signal. An ignition key-on event told the Datalogger to start recording data. An ignition key-off event told the datalogger to store all data on its internal hard drive. The stored file was labeled by its starting date and time. This stored file contains all raw data collected.

The ATDS system had sufficient capacity to record any single trip of approximately seven (7) hours duration in which the vehicle was operated continuously without an ignition key off event. This was based on the 2 Hz sampling rate of this project. For this project, a special timer circuit was added to allow the unit to turn itself on once per hour during periods of vehicle non-operation to record temperature data. This circuit functioned by simulating a key-on/key-off sequence. A second battery was used to prevent premature drainage of the vehicle battery.

The ATDS Datalogger used during for this project was a compact self-contained system. Physically this unit weighed 30 pounds and was 13 inches deep, 7 inches high, and 17 inches wide. The datalogger was located in each vehicle's trunk. To resist tampering by the participants, the datalogger was fitted with a keyed front panel cover to restrict access switches and the floppy drive. The unit was strapped in place during operation.

By using standard plug-in signal conditioning and linearizing modules, virtually any type of electrical signals can be recorded. These standard conversion modules are available for thermocouples, voltage, and frequency inputs. All conversion modules were calibrated with laboratory bench equipment after installation into the datalogger.

The dataloggers monitored vehicle transducer signals at a sampling rate of 2 Hz for the following parameters:

- Vehicle Speed
- Engine Speed
- Throttle Position
- Engine Coolant Temperature
- Manifold Absolute Pressure (MAP) or Mass Air Flow (MAF) depending on the available onboard vehicle transducer
- O_2 Sensor Voltage

By using specially prepared onboard computer wiring harnesses, datalogger connections to vehicle transducers were tapped from the tranducer signal line to the vehicle Engine Control Module (ECM). The onboard computer wiring harnesses were connected to the dataloggers using twist lock-on quick connectors.

Analog signals from the specially installed Air/Fuel Ratio sensor and K-type thermocouples were also recorded at 2 Hz. Thermocouples were installed in the inlet, midbed, and outlet of the catalyst. A thermocouple located on the rear bumper of each vehicle provided ambient temperature readings. The Air/Fuel Ratio sensor was an NGK universal oxygen sensor installed immediately upstream of the catalyst inlet. Table 3 lists the various parameters recorded, the source of the input signals, and the engineering unit they were converted to. Conversion factors for certain Toyota Camry parameters were unavailable and these parameters were left in the input signal units.

Table 3: Source and Conversion of Vehicle Parameters

Parameter	Source	Input Signal	Converted To:
Vehicle Speed	ECM	Frequency (Hz)	Miles per Hour
Engine Speed	ECM	Frequency (Hz)	Revolutions per Minute
Throttle Position	ECM	Voltage (VDC)	Percent Open
Engine Coolant Temperature	ECM	Voltage (VDC)	Degrees Farenheit
Manifold Absolute Pressure	ECM	Voltage (VDC)	Inches of Mercury
Mass Air Flow	ECM	Voltage (VDC)	Kilograms per Hour
Air/Fuel Ratio	UEGO/NGK Sensor	Voltage (VDC)	Air/Fuel Ratio
O_2 Sensor	ECM	Voltage (VDC)	None
Catalyst Inlet Temperature	K-Type Thermocouple	Voltage (VDC)	Degrees Farenheit
Catalyst Midbed Temperatures	K-Type Thermocouples	Voltage (VDC)	Degrees Farenheit
Catalyst Outlet Temperature	K-Type Thermocouple	Voltage (VDC)	Degrees Farenheit
Ambient Temperature	K-Type Thermocouple	Voltage (VDC)	Degrees Farenheit

Initially this contract required that one of these dataloggers be delivered to CARB at the end of the project. This unit was equipped as described above. Data retrieval procedures for this unit are described in the following section and in Appendix C. During the course of this contract, the next generation of the ATDS Datalogger was being developed. CARB decided to purchase the seven instrumented test vehicles and five of these next generation dataloggers.

The additional dataloggers were new generation units. These units provided enhanced set-up features, an interactive monitor view of the data being recorded, enhanced data acquisition capabilities, and a more efficient data storage technique. The physical dimensions of these units were the same as the original datalogger units. The enhanced set-up features allow for easier and quicker calibration and verification of the input signals. The interactive monitor allows settings to be viewed and changed in real-time. Data acquisition was enhanced through the time tagging of every data sample. The data storage concept was the most radical change. The hard disk and the floppy disk drives were replaced with a twenty-one megabyte floptical drive. This change was possible because of the new data storage philosophy employed in this generation of datalogger. The floptical approach also allowed for immediate data removal simply by extracting the floptical disk and replacing it with a formatted, blank floptical disk.

Concurrent with the conduct of this research project for the Air Resources Board, ATDS embarked upon a downsizing and capabilities enhancement project for the datalogger system. The newly developed ATDS Datalogger has the following improvements over the version used for this project:

- Physical size reduced by 70 percent.
- Mass reduced by 14 percent.
- Number of active channels tripled to 48.
- Individual channels now sample rate selectable.
- Data storage techniques provide 8 percent capacity improvement.

A technical brochure describing the newest version of the ATDS Datalogger is included in Appendix B for reference.

Vehicle Deployment and Data Collection

Each test vehicle was loaned to a subset of participants of CARB's In-Use Light Duty Vehicle Surveillance Project Series-12. Each participant drove the instrumented vehicle for at least 7 days each. This Surveillance Project used randomly generated lists of Vehicle Identification Numbers (VINs) to select vehicles from the South Coast Air Basin in-use fleet to be tested at CARB's Haagen-Smit Laboratory. Vehicle owners were contacted through a first class mailing. If this was unsuccessful, a telephone contact was initiated. The entire vehicle procurement procedure is summarized in the "Test Report of the Light Duty Vehicle Surveilance Program Series-12", Report Number MS-94-04, July 1994.

The selection process produced participants from four counties. 56.3% of the participants resided in Los Angeles County, 28.1% resided in Orange County, 8.3% resided in San Bernardino County, and 7.3% resided in Riverside County. Appendix D lists the vehicle type and the home city of each participant. An attempt was made to exchange each instrumented car with a similar type participant's car.

Information given to the participants regarding the purpose of the dataloggers was kept general in order to minimize influencing their driving behavior. Some may argue that driving behavior changes when motorists use cars that do not belong to them. However, a point can also be made for the opposite—that driving behavior does not change and loaned cars are better taken care of so as to avoid liability for damages.

At the end of each loan period, the vehicle was returned to the ATDS headquarter in Ontario, California. Recorded data in the form of the series of trip files were extracted. The vehicles were then prepared for the next participant. Data extraction procedures are shown in Appendix C.

DATA ANALYSIS

The following are discussions of the data analysis. These discussions are organized by recorded and calculated vehicle parameters.

96 sets of data were collected. Over 5000 trip files were available for computer analysis. Each trip file contained data of all recorded channels from a key on to key off sequence. Quality checking of the data involved excluding any channel containing excessive amounts of zero, missing, or out of bound data. The number of trip files used for analysis of each parameter varied because different trip files may have had different channels rejected. Files were grouped by vehicles and subgrouped by participants. Data processing was done using the SAS statistical analysis software and frequency distribution graphs were generated for the following:

- Trip Length (miles—weekdays, weekends, and all days)
- Trip Duration (minutes)
- Vehicle Speed (mph—weekdays, weekends, and all days)
- Acceleration (mph/sec)
- Air Fuel Ratio
- Throttle Position (% open)
- Mass Air Flow or Manifold Absolute Pressure (kg/hr, in. Hg, or Volts)
- Catalyst Temperature (° F)
- Ambient Temperature (° F)
- Fuel Tank Skin Temperature (° F)
- Soak Time (hours)
- Time in Mode (idle, cruise, acceleration, and deceleration)
- Transition from Mode (idle to acceleration, cruise to acceleration, cruise to deceleration, acceleration to cruise, acceleration to deceleration, deceleration to acceleration, deceleration to cruise, and deceleration to idle)
- Distribution of Trips by Starting Time
- Distribution of Trips by Day of Week

Further reduction of data was accomplished by combining participants for each vehicle and generating vehicle level histograms for the above parameters. This method produced weighted histograms in which data from participants who drove more frequently will have a greater impact on the final result. Final analysis was done by processing the vehicle level data with the Quattro Pro spreadsheet software. The average of all seven vehicles obtained in this final analysis was unweighted. Other analytical subroutines can be performed at leisure since the ATDS datalogger saves all data in a raw format. No onboard processing was done.

Trip Length/Trip Duration

Important indicators of driver influence are trip length and trip duration. A trip is defined as the period of engine on operation between engine on and engine off. Table 4 shows the average trip length for weekdays, weekends, and all days, and trip duration for all days.

Table 4: Average Trip Lengths and Trip Duration

Vehicle	Weekday Trip Length (miles)	Weekend Trip Length (miles)	All Days Trip Length (miles)	Average Trip Duration (minutes)
Ford Taurus	8.2	6.9	7.9	13.7
Ford Tempo	5.4	4.0	5.1	11.8
Chevrolet Lumina	8.3	8.8	8.4	15.2
Chevrolet Astro Van	6.6	7.2	6.7	12.4
Pontiac Grand Am	8.4	10.4	8.9	13.9
Honda Accord	6.8	5.3	6.5	13.7
Toyota Camry	9.7	9.9	9.7	14.3
Unweighted Average	**7.6**	**7.5**	**7.6**	**13.6**

Graphs 1A, 1B, and 1C are plots of trip length vs. percentage of operation for all vehicles during weekdays, weekends, and all days respectively. Graph 2 is a plot of trip duration vs. percentage of operation for all vehicles. Note that most trips were less than 20 miles in length.

Data for all vehicles showed many trips which were less than a mile in length. These short trips are significant in that they do not permit sufficient time for a cold emissions system to become operational. Emissions per mile from these short trips may be greater than other trips. Specifics of these short trips were not known—it is unclear whether they were the result of moving cars in the driveway, driving down the street, or a combination of many situations. The percentage of trip lengths which were less than a mile are shown in Table 5.

Table 5: Trip Lengths Less Than One Mile—Percentage of All Vehicle Operation

Vehicle	Weekday Percentage	Weekend Percentage	All Days Percentage
Ford Taurus	29	22	27
Ford Tempo	42	35	40
Chevrolet Lumina	30	35	31
Chevrolet Astro Van	34	32	33
Pontiac Grand Am	31	26	29
Honda Accord	31	33	32
Toyota Camry	27	28	27
Unweighted Average	**32**	**30**	**31**

Time of Day/Day of Week

The date and time stampings of datalogger files were used to analyze the distribution of vehicle operation by time of day and day of week. Findings from the analysis are:

- Operating time was greatest between 11 am and 3 pm with the peak usage time at 1 pm (see Graph 3).
- Operating time was lowest at 11 pm.
- The vehicles averaged 7.2 trips per day (see Graph 5).
- Mondays had the lowest average number of trips with 6.5 trips per day.
- Saturdays had the highest average number of trips with 7.8 trips per day.
- The average miles per day driven was 49 miles.
- Saturday had the highest average miles per day driven with 56 miles.
- Sunday had the lowest average miles per day driven with 40 miles.

Graph 3 is a plot of trip starting time for all vehicles. Graph 4 is a plot of non-normalized day of week usage for all vehicles. The graph shows that the number of trips taken on Monday was less than other weekdays. Because of the non-normalized data used in this graph (i.e., the graph does not account for the possibility the vehicles may have not been with a participant at all times), skewing of data may have resulted and the graph's value in reaching a conclusion is limited. Graph 5 is a plot of average miles and trip per day for all the days of the week. Additional computing time was used to produce this graph. Graph 5 takes into account only the time during which the vehicles were with a participant and better reflects real-world driving habits.

Graphs 6A to 6G are three-dimensional plots of time of day vs. day of week usage grouped by vehicles. Most tall peaks representing a high number of trips are situated in the middle section of these plots. The graphs shows that most trips were taken during the midday of weekdays.

Soak Time

Soak time was determined by calculating the duration between a key-off and next key-on. Besides influencing catalyst performance, soak time also provided a measure of how long the evaporative canister has been exposed to diurnal fuel losses.

Federal Test Procedure data showed that vehicle emissions in the initial few minutes after a cold start are substantially higher than after a hot start because of the time required for the emissions system components to reach operating temperature. The standard definition of a "cold start" is a start after a vehicle has soaked for at least one hour. Using this definition, the percentage of cold starts for each vehicle was calculated from the data shown in Graph 7. Table 6 shows the percentage of cold starts, soak times less than 10 minutes, and soak times more than 1, 2 & 3 days for each vehicle. The unweighted averages for all seven vehicles are also shown.

Table 6: Percentage of Cold Starts & Soak Times Under 10 Minutes/Over 1/2/3 Days

Vehicle	% of Cold Starts (Soak Time > 1 hr.)	% of Soak Times Less Than 10 Min.	% of Soak Times Over 1/2/3 Days		
Ford Taurus	37	31	9.8	1.5	1.2
Ford Tempo	38	30	6.3	1.0	0.4
Chevrolet Lumina	41	30	10.5	1.6	0.4
Chevrolet Astro Van	39	30	9.6	1.4	0.2
Pontiac Grand Am	38	33	7.3	0.3	0.3
Honda Accord	43	31	9.3	1.0	0.4
Toyota Camry	40	35	9.8	1.1	0.2
Unweighted Average	**40**	**31**	**8.9**	**1.1**	**0.4**

An assumption was made that the frequency distribution bin value represented the 50% percentile for that bin. For example, the 60 minute bin contained all data points with values between 50 minutes and 70 minutes, and it was assumed that 50% of all data points were between 50 minutes and 60 minutes and the remaining 50% were between 60 minutes and 70 minutes.

In comparison to the current inventory model's estimate of 60.4% cold starts, the data from this study showed that only 40% of all starts were cold.

The ATDS datalogger can turn itself on approximately once per hour to record parameters during periods of vehicle non-operation. This feature was used to monitor the decline in catalyst midbed temperature after engine off. Graphs 8A to 8G plot catalyst midbed temperature as recorded by the midbed #1 thermocouple after engine off vs. time for all seven vehicles. The data for these graphs include both the ATDS datalogger's once per hour internal timing record of the catalyst midbed temperature and the first midbed temperature reading at a key-on event. Using a midbed temperature of 500°F (an assumed light-off temperature for the catalyst) as the limiter between hot and cold starts, it was observed that the one hour soak "cold start" assumption is valid for an average trip with a hot catalyst. After one hour, most catalyst data points indicated midbed temperatures below 500°F.

Vehicle Speed/Acceleration

Vehicle speed was recorded directly from the vehicle's onboard speed transducer. Frequency distributions for all vehicles showed a trimodal operating characteristic. By "trimodal" it is meant that three peaks in the frequency distributions were noted. These peaks represented the three modal values. The lowest value mode represented the idle time of each vehicle. The middle value mode represented the city cruising speed, and the highest value mode represented the highway cruising speed. Table 7 shows the average vehicle speed for weekdays, weekends, and all days.

Table 7: Average Vehicle Speed

Vehicle	Weekday Avg. Speed (mph)	Weekend Avg. Speed (mph)	All Days Avg. Speed (mph)
Ford Taurus	34	34	34
Ford Tempo	28	27	28
Chevrolet Lumina	32	35	33
Chevrolet Astro Van	32	37	33
Pontiac Grand Am	33	38	34
Honda Accord	30	28	29
Toyota Camry	40	46	41
Unweighted Average	**33**	**35**	**33**

Graphs 9A, 9B, and 9C are plots of vehicle speed vs. percentage of operation for all vehicles during the weekdays, weekends, and all days respectively. Data in these graphs were slightly distorted due to a signal conditioner module in the Pontiac Grand Am datalogger which limited the top recorded speed to 70 mph. This made the peak at 70 mph on the graphs appear more significant than actual. The zero value data above 70 mph for the Pontiac was not used in calculating the average. The signal conditioner modules in the remaining vehicles limited the top recorded speed to 110 mph.

Acceleration or delta speed was obtained by calculating the change in vehicle speed from one data sample to the next. The acceleration value may be of interest as vehicle emissions are typically higher during acceleration. Driver aggressiveness was analyzed by calculating the percentage of heavy acceleration—defined here to be greater than 5.5 mph/s—of all vehicle operations, and of all acceleration mode. The results are shown in Table 8.

Table 8: Frequency of Heavy Acceleration

Vehicle	Percentage of All Operation	Percentage of All Acceleration Mode
Ford Taurus	0.7	2.7
Ford Tempo	0.9	4.0
Chevrolet Lumina	0.8	2.3
Chevrolet Astro Van	0.6	2.2
Pontiac Grand Am	0.6	2.7
Honda Accord	1.7	6.3
Toyota Camry	4.1	11.8
Unweighted Average	**1.3**	**4.6**

Graph 10 shows acceleration vs. percentage of operation for all vehicles. Acceleration / deceleration data was broken down into 0.5 mile per hour per second bins. Data was calculated for accelerations and decelerstions as high as 12 miles per hour per second, but the bins for delta speed greater than 6.0 miles per hour per second and less than -6.0 miles per hour per second represent less than 0.1 per cent per bin of actual operation.

Catalyst Inlet/Outlet & Midbed Temperatures

Catalyst inlet and outlet temperatures indicate engine operating conditions and loads. Their value lies mainly in identifying any abnormal engine conditions such as excessive rich or lean operation. Data from this study showed no such abnormality.

Catalyst midbed temperature is an important factor influencing emissions system durability. To measure catalyst midbed temperature, thermocouples were installed in the catalytic converter brick(s) of each vehicle and identified as midbed #1 and midbed #2 thermocouples. The midbed #1 thermocouples were closer to the catalyst inlet than the midbed #2 thermocouples. The Toyota Camry and Chevrolet Astro Van do not have a second midbed and therefore did not have a midbed #2 thermocouple installed.

Graphs 11A to 11G are plots of average catalyst temperatures vs. percentage of operation. The midbed #2 thermocouples on the General Motor and imported vehicles read higher temperatures than the midbed #1 thermocouples. A possible explanation is that a different control strategy employed by these manufacturers placed greater burden on the second catalysts. However, lack of data from the manufacturers regarding their emissions system prevents support of a detailed explanation of this phenomenon.

Ambient Temperature & Fuel Tank Skin Temperature

Ambient temperature influences a vehicle's evaporative emissions. Identifying the temperature when a vehicle is most likely to be used may assist in the planning of evaporative emissions standards and testing procedures. Note that ambient temperature does not necessarily mean the air temperature. A vehicle which was driven under the sun in heavy traffic in the sun can generate ambient temperature data above the air temperature. On all vehicles, the ambient temperture probe was installed out of the air stream in the rear bumper. The unweighted average ambient temperature for all seven vehicles was 68° F.

The fuel tank skin temperature profile can also assist in the planning of evaporative emissions standards and testing procedures. It was observed that the average fuel tank skin temperature can be significantly higher than ambient. The tank skin averaged 5.6° F above ambient and reached as high as 18° F above on the Toyota Camry. Table 9 shows the difference between fuel tank and ambient temperatures. Although ambient temperature influences fuel tank skin temperature, other factors must be considered as well. These factors include radiated and reflected heat from the road surface and the proximity of the fuel tank to the exhaust or other systems which generate heat.

Table 9: Difference Between Fuel Tank Skin and Ambient Temperatures

Vehicle	Fuel Tank Skin minus Ambient Temperature (Average,° F)
Ford Taurus	0
Ford Tempo	5
Chevrolet Lumina	-3
Chevrolet Astro Van	1
Pontiac Grand Am	10
Honda Accord	7
Toyota Camry	18

Graph 12 shows ambient and fuel tank skin temperatures vs. percentage of operation.

Engine Coolant Temperature

Data for engine coolant temperature was obtained from the vehicle's onboard sensor. Graph 13 plots engine coolant temperature for all vehicles vs. percentage of operation. All vehicles showed a modal engine coolant temperature between 150° F and 220° F which was in the range of normal coolant operating temperature indicating that the thermostats were functioning normally. No vehicles exhibited any excessive time spent in the above normal temperature range. Table 10 lists the average engine coolant temperature for each vehicle.

Table 10: Average Engine Coolant Temperature

Vehicle	Average Engine Coolant Temperature (° F)
Ford Taurus	193
Ford Tempo	190
Chevrolet Lumina	180
Chevrolet Astro Van	187
Pontiac Grand Am	149
Honda Accord	162
Toyota Camry	215

Engine Speed/Air Fuel Ratio/Oxygen Sensor

Engine speed is an indicator of driver input and conditions within the engine which influence downstream systems. No abnormal conditions such as excessive rich or lean times were noted in any vehicles. Graph 14 is a plot of engine speed vs. percentage of operation. Two modes are shown on the graph. The lower value mode corresponds to the idle engine speed while the higher value mode represents the "cruising" engine speed. Cruising can be either at city speed in a middle gear or at highway speed in top gear.

Air/Fuel Ratio (AFR) readings in all vehicles were measured by an NGK universal oxygen sensor installed immediately upstream of the catalyst inlet. The AFR data also indicated no abnormal rich or lean operation in any vehicles. Findings from analysis of the data were:

- ❑ All vehicles showed stoichiometric or near stoichiometric operation with a prominent modal ratio of 14.7.
- ❑ Extremes of the data may indicate two other modes. This was due to the distortion caused by truncation at the lowest and highest bins.

The Ford Taurus and Toyota Camry AFR data showed another mode at a ratio of 13.3 to 13.4. This is probably a result of a run rich open loop algorithm which may have been used.

Graphs 15 plots AFR vs. percentage of operation for all vehicles.

The oxygen sensor acts as a voltage source and series resistance. A functional oxygen sensor will produce a reading of 0.0 V to 0.4 V under a lean of stoichiometric air/fuel ratio. A rich mixture result will in a reading between 0.6 V and 1.0 V. The sensor will read zero until it warms.

All vehicles showed a bimodal operation with modes at the rich and lean voltage ranges. The bimodal nature of the frequency distribution was due to the systematic sampling rate of the datalogger and the apparent resident time associated with the continuously moving control algorithm. The data for all vehicles showed an active control system targeting a stoichiometric operation.

Graph 16 plots oxygen sensor voltage vs. percentage of operation for all vehicles. Note that outliers were from General Motor vehicles. This may be a result of a different control algorithm used in these vehicles.

Throttle Position

Throttle position, engine speed, and acceleration are closely related. Because the response to throttle input vary from vehicle to vehicle, throttle position's value lies mainly in being used to verify engine speed, acceleration, and mode of operation data, all of which indicate actual vehicle response. Similar to engine speed, frequency distributions of throttle position showed two modes corresponding to the idle and cruising modes of the vehicle. The time at zero percent throttle was also very close to the time spent in idle and deceleration modes. Graph 17A is a plot of throttle opening vs. percentage of operation. Graph 17B expands the scale of Graph 17A for throttle openings above 30%. No significant throttle operation between 30% and 80% was found. The mode at the 80% end of the graph resulted from data truncation.

Mass Air Flow/Manifold Absolute Pressure

Mass Air Flow (MAF) and Manifold Absolute Pressure (MAP) indicate engine load but are specific to vehicle and engine size. Either MAF or MAP was recorded depending upon each vehicle's available onboard transducer. Their value in determining overall usage profile and driving habits is limited.

Graphs 18A and 18B plot MAF and MAP as recorded from the instrumented vehicles.

Mode Analysis

The time that the vehicles spent in certain modes was identified through analysis of vehicle speed. These modes were defined in meetings between ATDS and CARB to be as follow:

- ❑ Idle - the period during which vehicle speed is 0 mph.
- ❑ Cruise - the period during which the vehicle speed differed by less than ± 0.5 mph/sec and vehicle speed at the end of the period differed from the speed at beginning of the period by less than ± 2.5 mph.
- ❑ Acceleration - the period during which the vehicle speed increased by at least 0.5 mph/sec.
- ❑ Deceleration - the period during which the vehicle speed decreased by at least 0.5 mph/sec.
- ❑ Cruise Acceleration - a cruise period in which the average vehicle speed increased from the starting speed by more than 2.5 mph.
- ❑ Cruise Deceleration - a cruise period in which the average vehicle speed decreased from the starting speed by more than 2.5 mph.

The time spent in cruise acceleration and cruise deceleration was less than 1% of total operation for all vehicles. Time spent in idle, cruise, acceleration, and deceleration varied greatly from participant to participant and vehicle to vehicle. The analysis of time spent in each mode may indicate specific road conditions experienced by the drivers. For example, a frequency distribution showing a large percentage of time spent idling, accelerating, and decelerating could indicate stop and go traffic while a distribution showing a large percentage of time spent cruising could indicate open road driving. Both patterns were observed in this program.

Analysis of throttle position data supported the mode of operation findings. Occcurances of zero percent throttle opening (46%) correlated with the percentage of time spent in idle and deceleration.

Graph 19 shows the "all vehicle" average percentage of operation for each defined mode. Note that the time spent in idle (22%) correlated with the time at idle speed shown on the vehicle speed plots (Graphs 1A, 1B, and 1C).

Mode Transition Analysis

Analysis of vehicle operation modes was extended to identify the frequency of transition between each mode. Findings from the mode transition analysis are:

- Seven significant transitions were identified. These transitions were:
  - Idle to Acceleration
  - Cruise to Acceleration
  - Cruise to Deceleration
  - Acceleration to Cruise
  - Acceleration to Deceleration
  - Deceleration to Idle
  - Deceleration to Cruise
- These seven transitions accounted for more than 99% of all transitions.
- The cruise to acceleration, cruise to deceleration, acceleration to cruise, and deceleration to cruise transitions accounted for at least 20% each of all transition occurances.
- The idle to acceleration, acceleration to deceleration, and deceleration to idle transitions accounted for no more than 5% of all transition occurances.

Graph 20 shows the percentage of all transition modes for the seven most significant transitions noted. Graph 21 is a time-speed plot showing examples of mode transition.

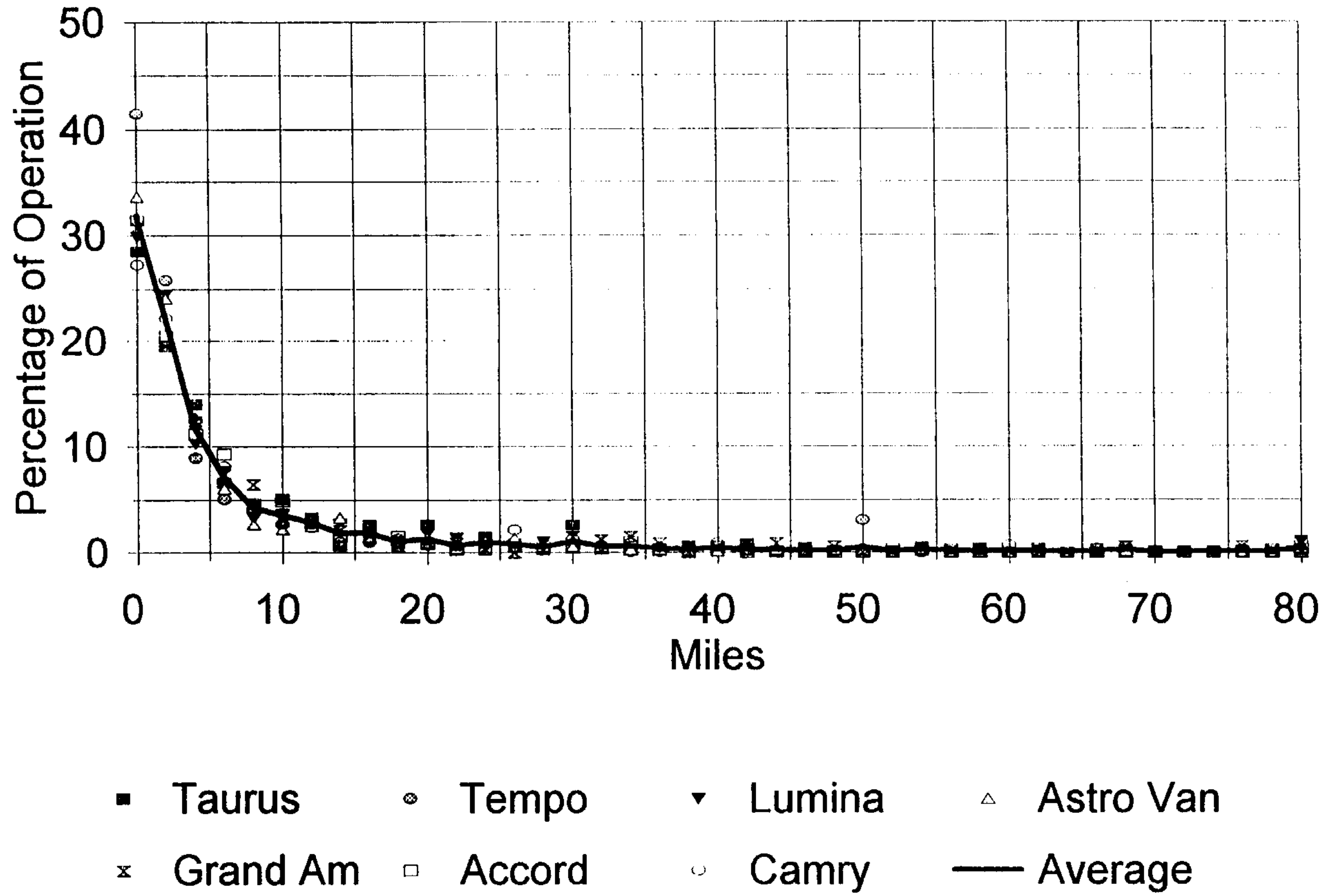
REFERENCE

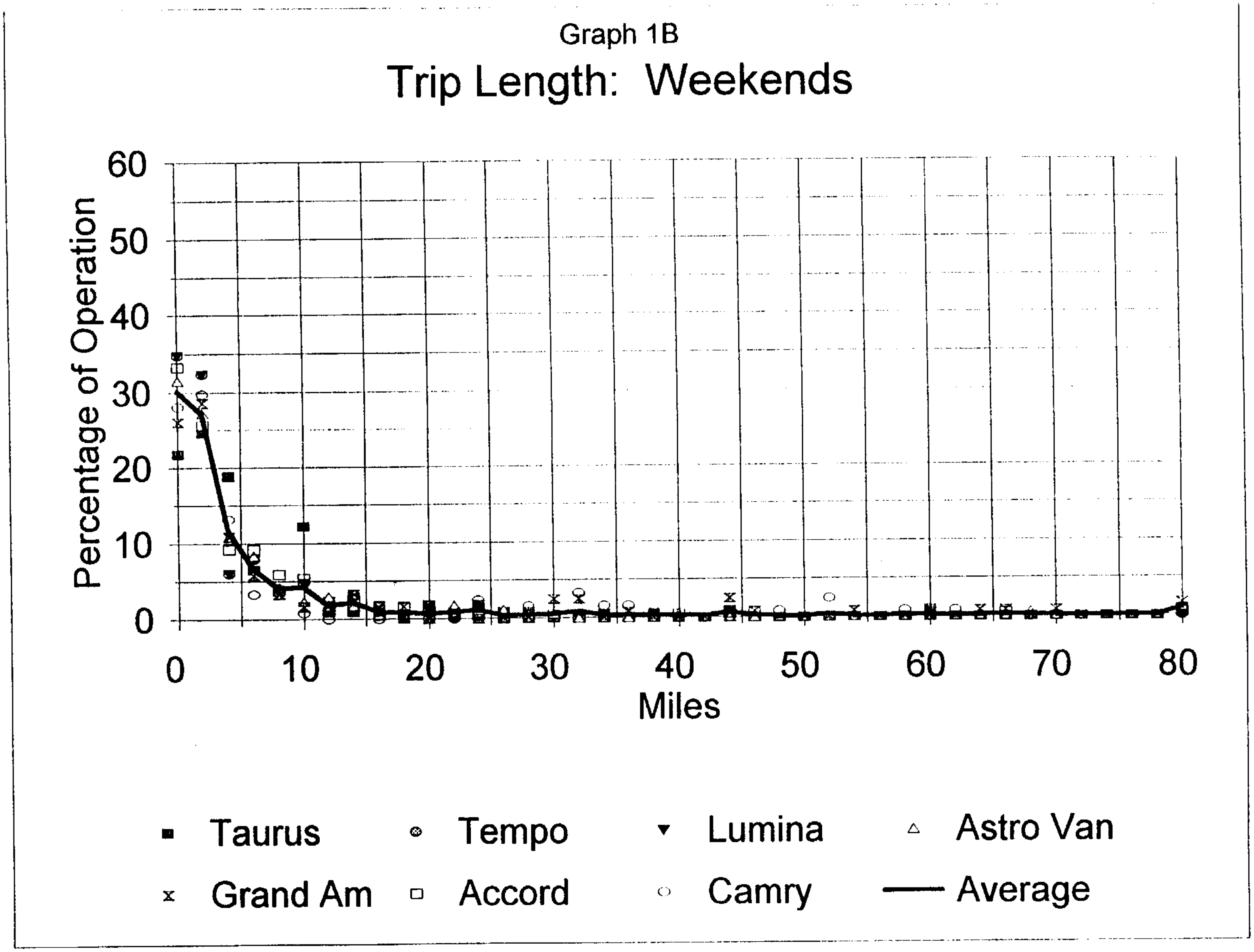
Magbuhat, S. & Long, J.R. "Using Instrumented Vehicles to Improve Activity Estimates For the California Emissions Inventory Model." Presented at the Air and Waste Management Association Conference, Raleigh, North Carolina, November 1, 1994.

APPENDIX A: GRAPHS

Graph 1A

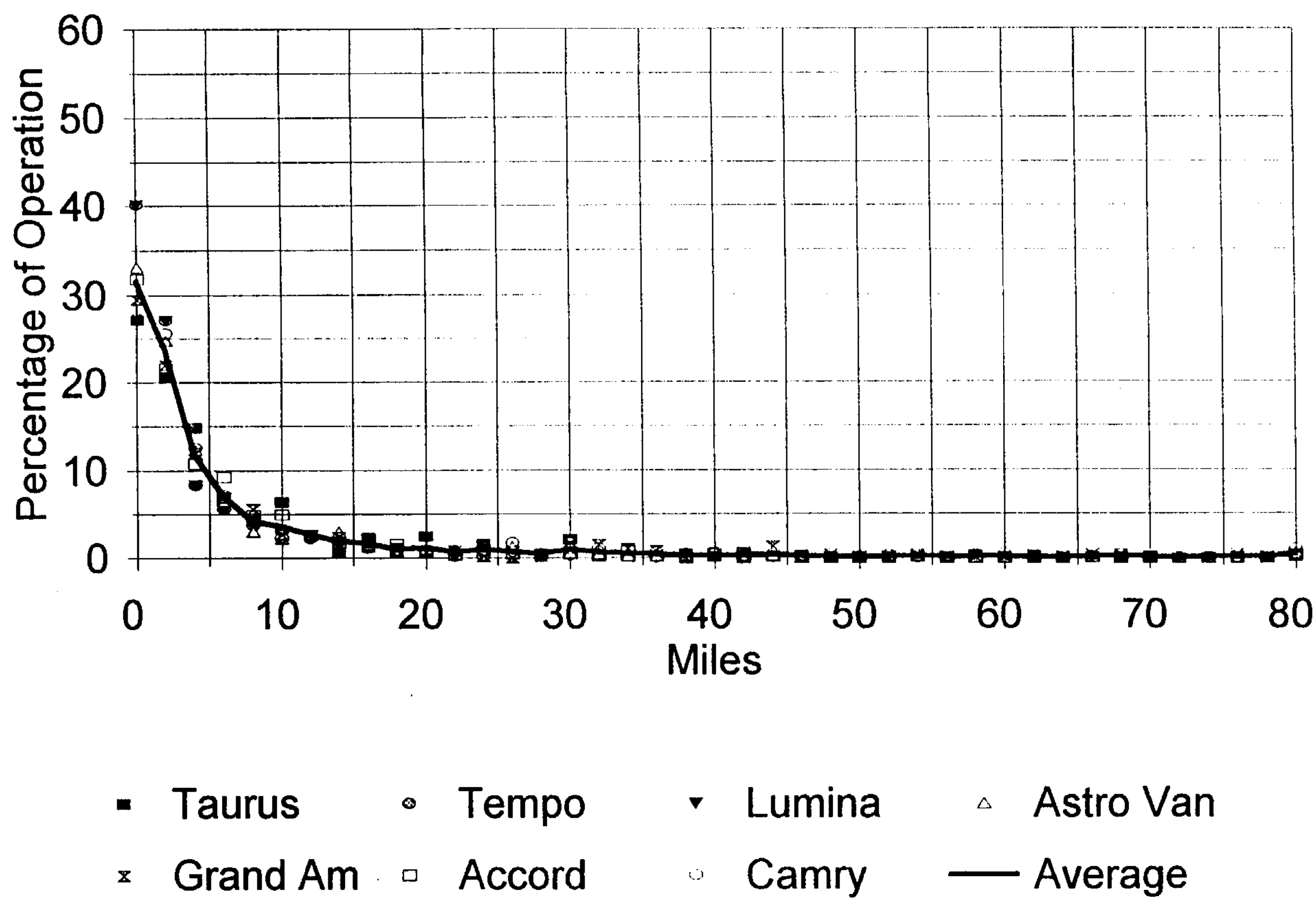
Trip Length: Weekdays



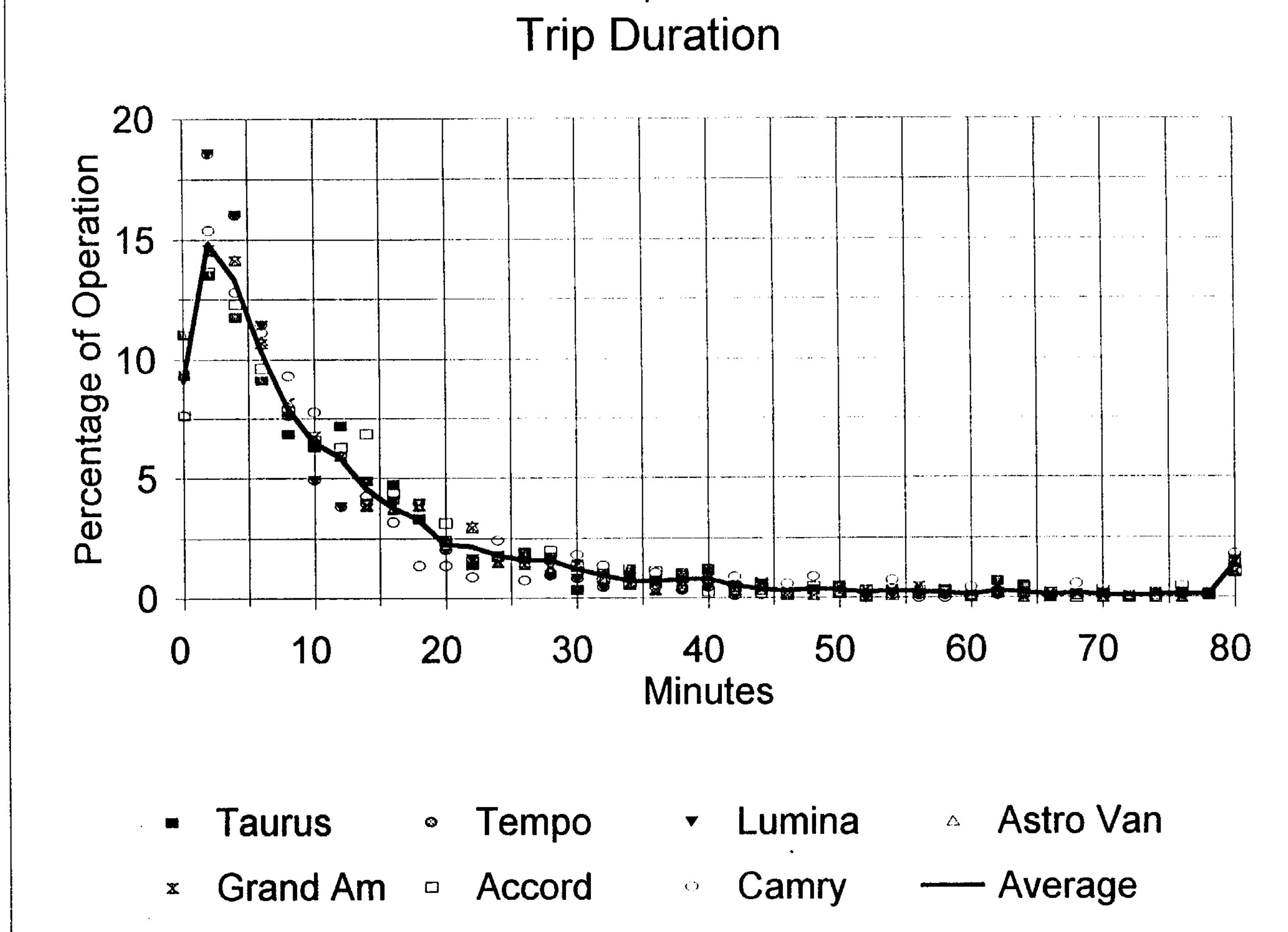

Graph 1B
Trip Length: Weekends
Percentage of Operation
60
50
40
30
20
10
0
0
10
20
30
40
50
60
70
80
Miles
Taurus
Tempo
Lumina
Astro Van
Grand Am
Accord
Camry
Average

Graph 1C

Trip Length: All Days

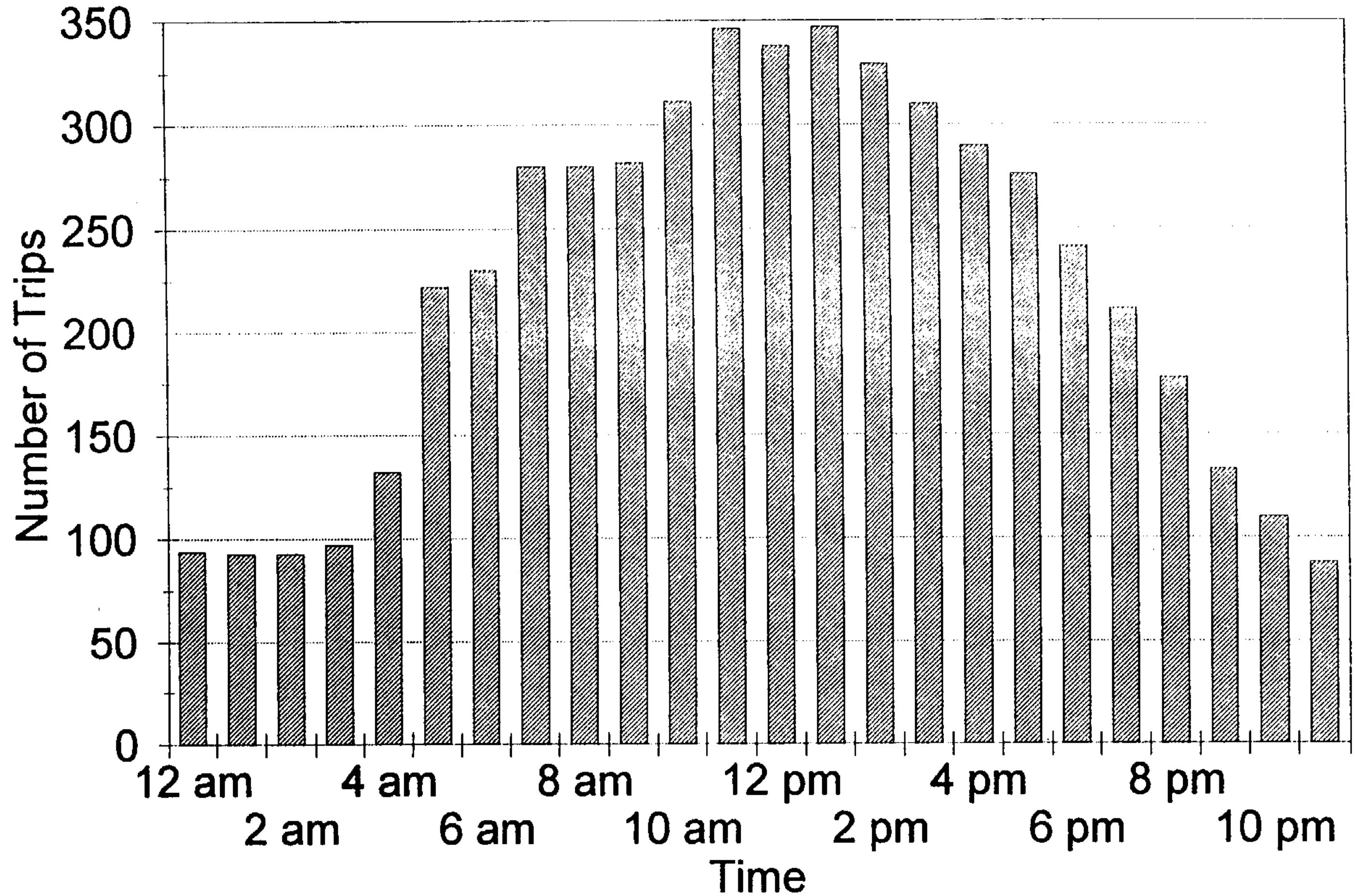


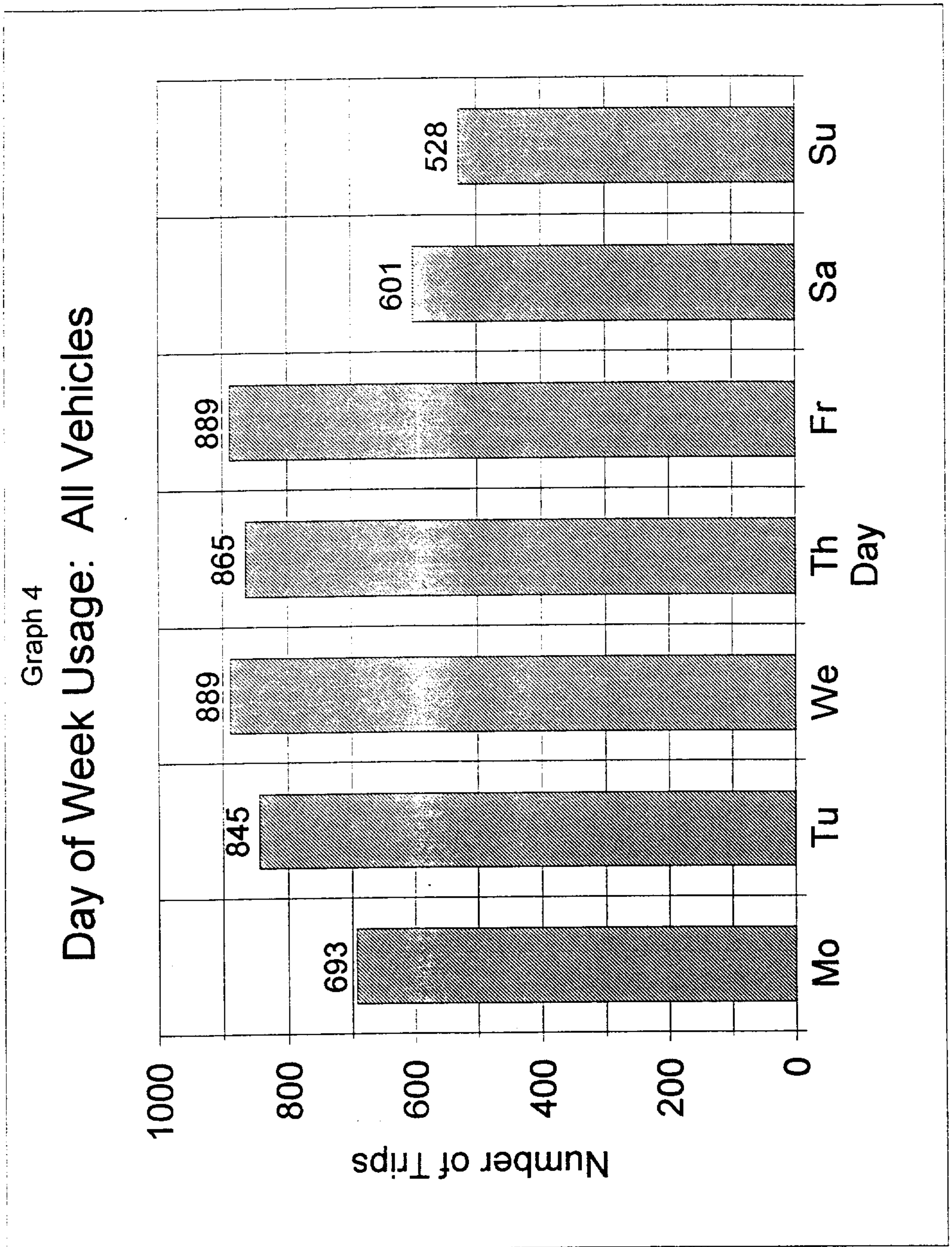
Graph 2


Trip Duration
Percentage of Operation
20
15
10
5
0
0
10
20
30
40
50
60
70
80
Minutes
Taurus
Tempo
Lumina
Astro Van
Grand Am
Accord
Camry
Average

Graph 3

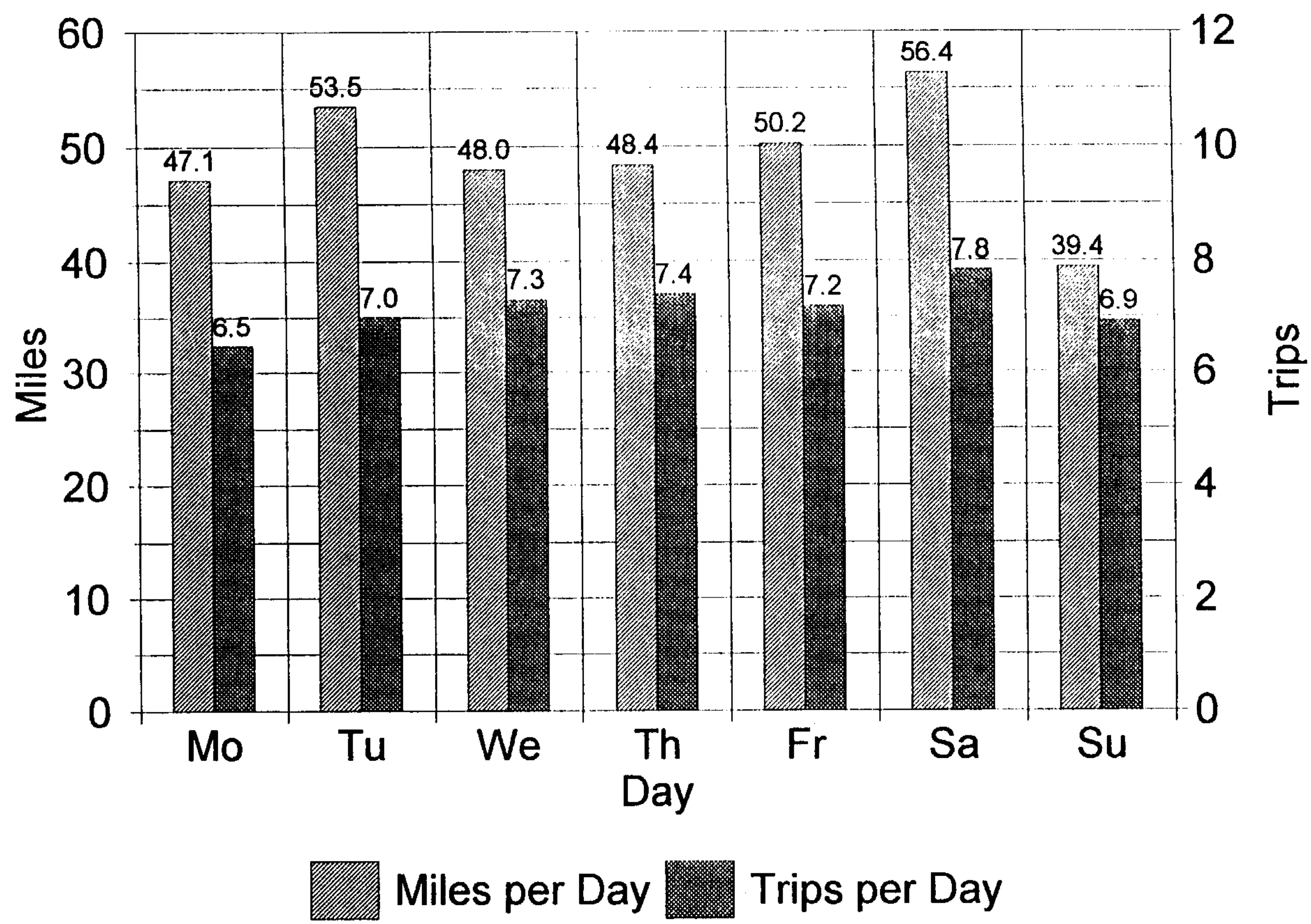
Trip Starting Time: All Vehicles




Graph 4
Day of Week Usage: All Vehicles
Number of Trips
1000
800
600
400
200
0
693
845
889
865
889
601
528
Mo
Tu
We
Th
Fr
Sa
Su
Day

Graph 5

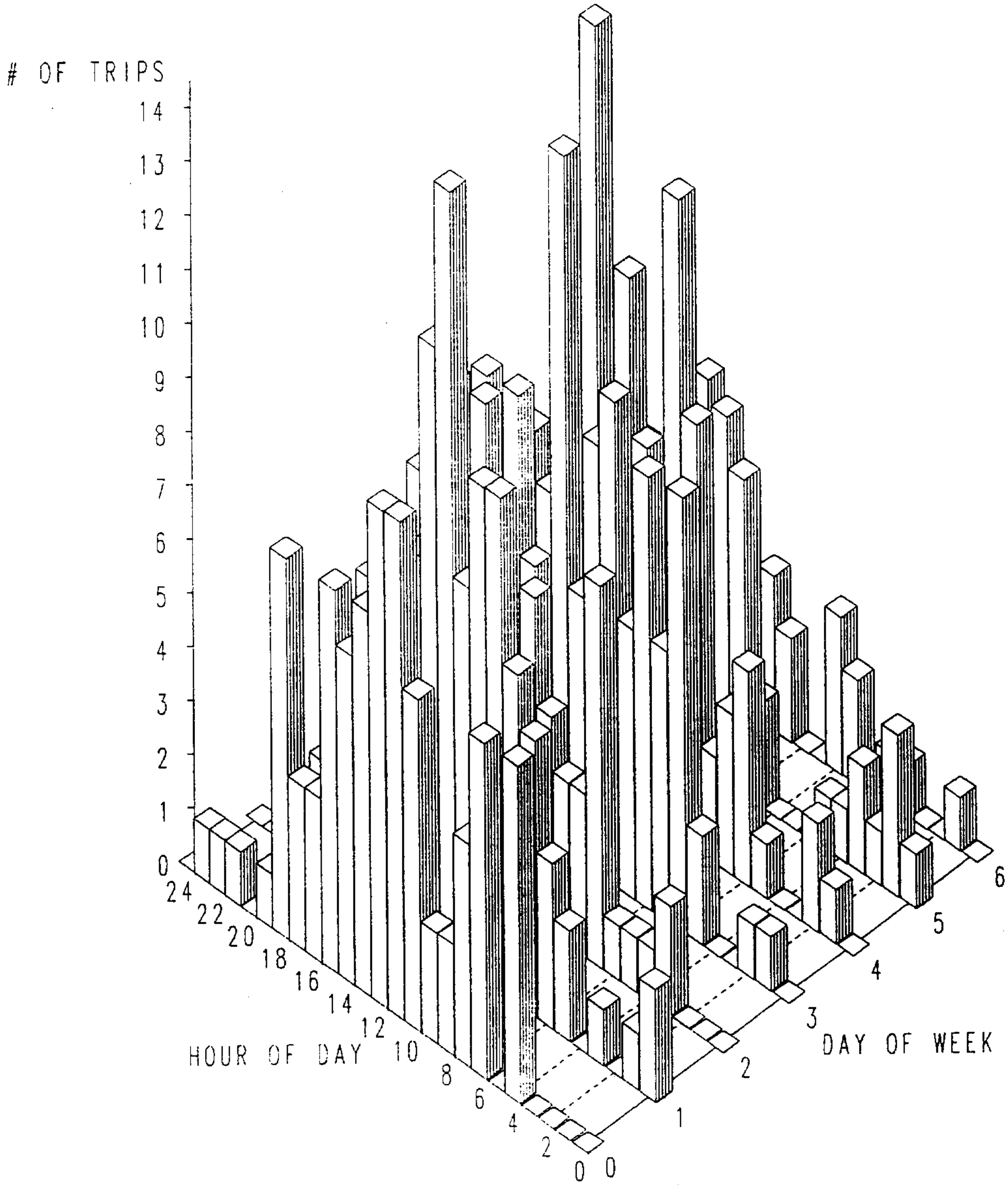
Average Miles & Trips per Day



Graph 6A

FORD TAURUS CAR# 334-1

START TIME V.S. DAY OF WEEK ANALYSIS
ALL PARTICIPANTS

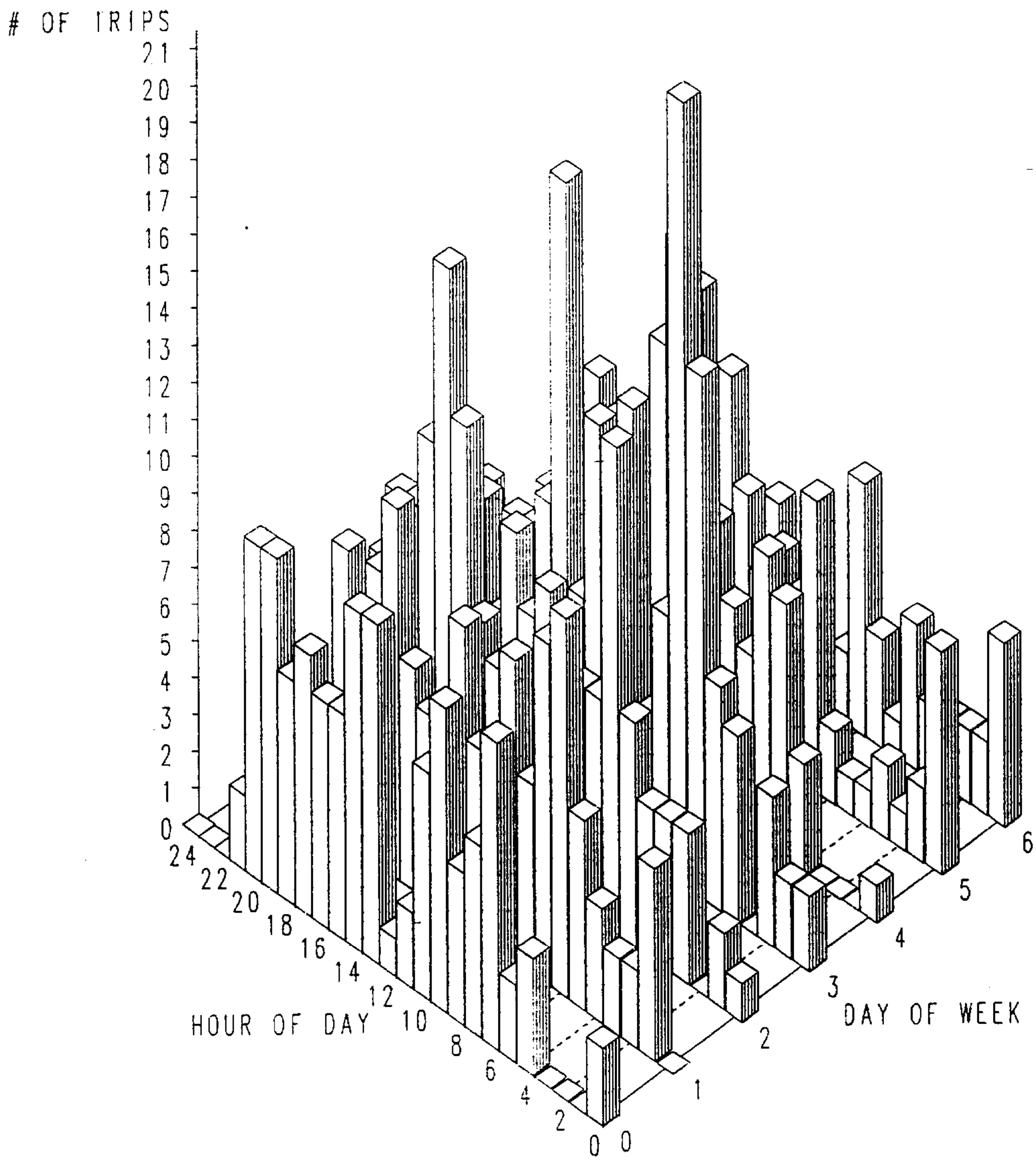


DAY OF WEEK = 0 = MONDAY, 1 = TUESDAY, ... 6 = SUNDAY

Graph 6B

FORD TEMPO CAR# 334-2

START TIME V.S. DAY OF WEEK ANALYSIS
ALL PARTICIPANTS

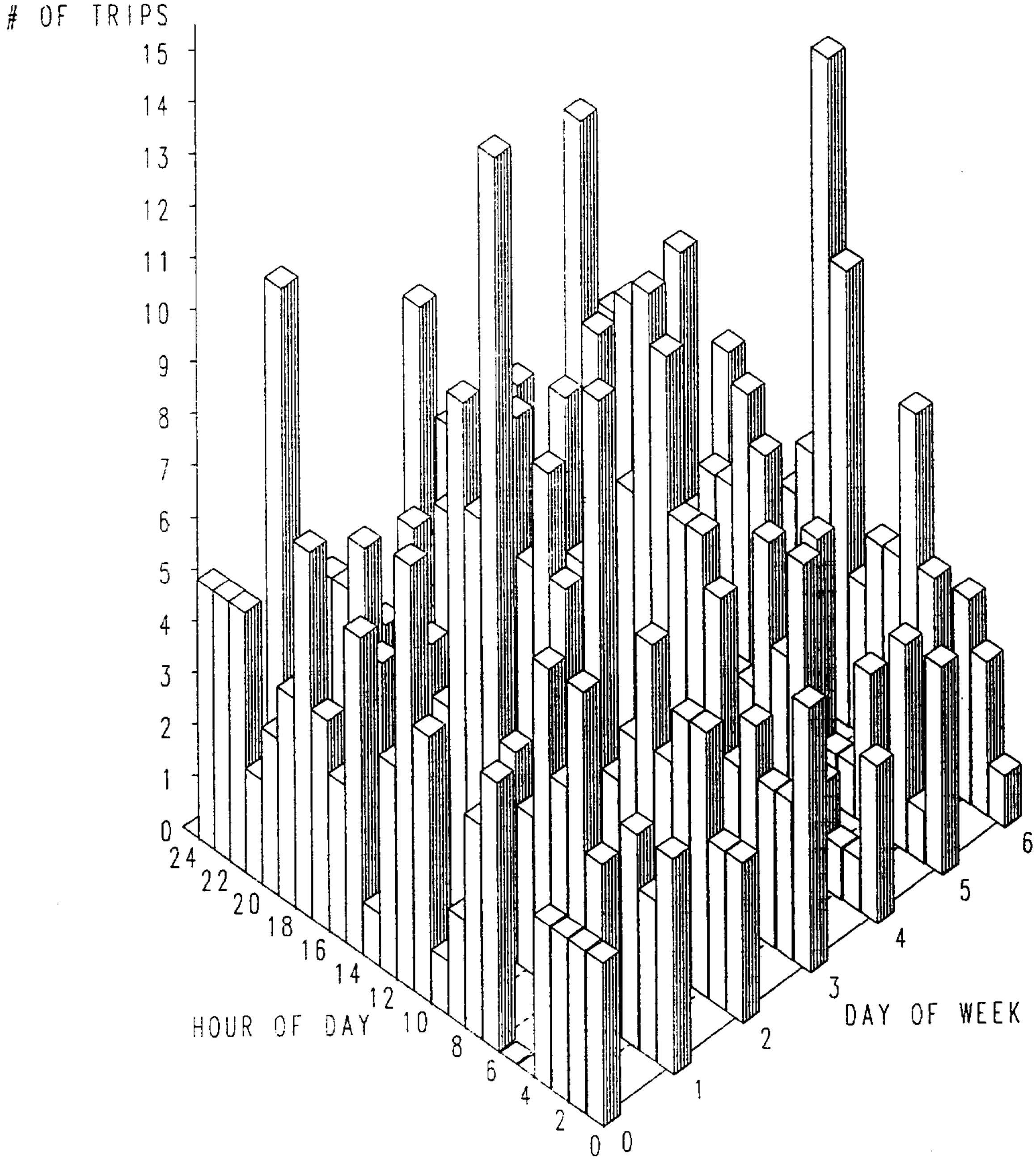


DAY OF WEEK = 0 = MONDAY, 1 = TUESDAY, ... 6 = SUNDAY

Graph 6C

CHEVROLET LUMINA CAR# 334-3

START TIME V.S. DAY OF WEEK ANALYSIS
ALL PARTICIPANTS

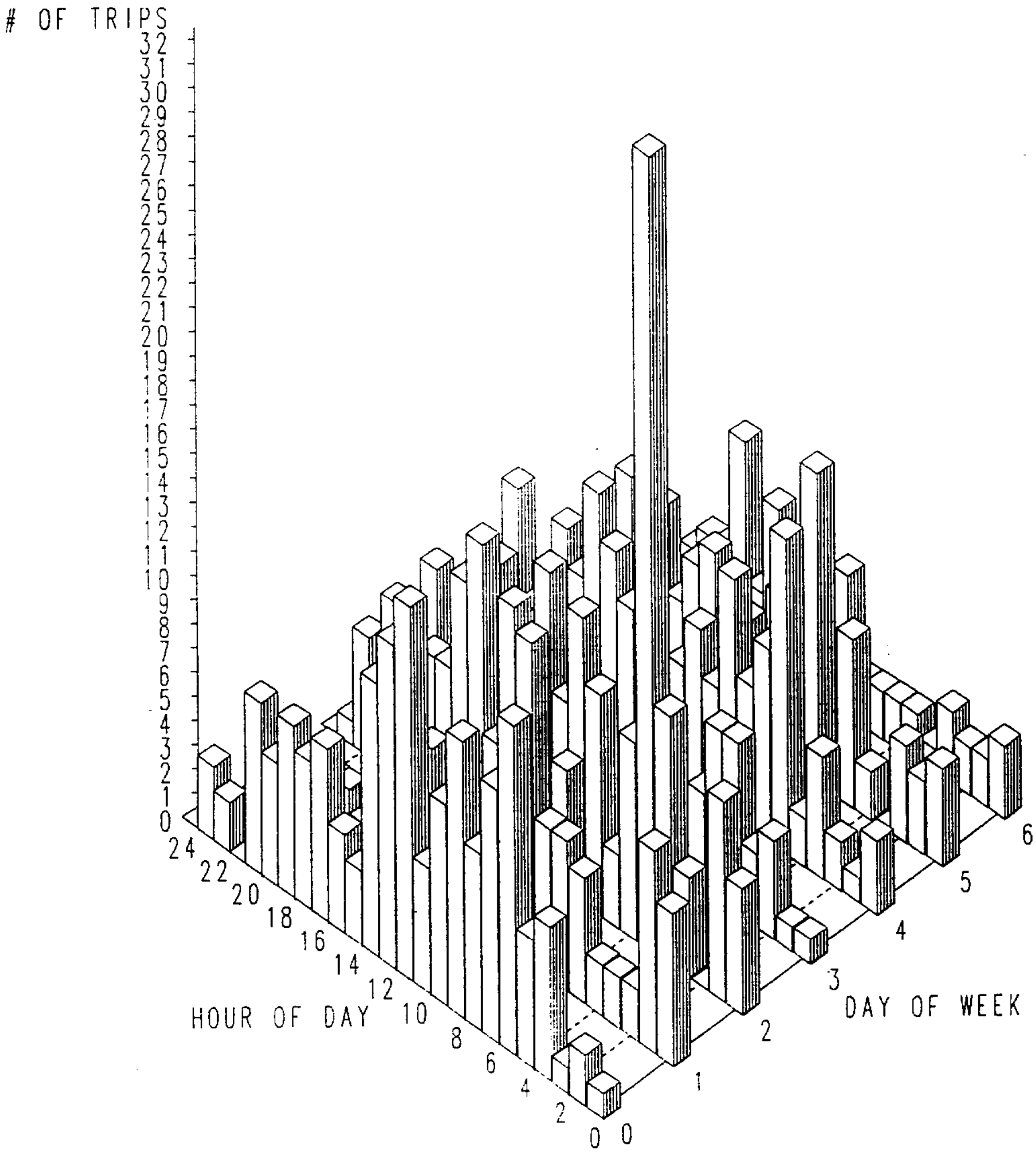


DAY OF WEEK = 0 = MONDAY, 1 = TUESDAY, ... 6 = SUNDAY

Graph 6D

CHEVROLET ASTRO VAN CAR# 334-4

START TIME V.S. DAY OF WEEK ANALYSIS
ALL PARTICIPANTS

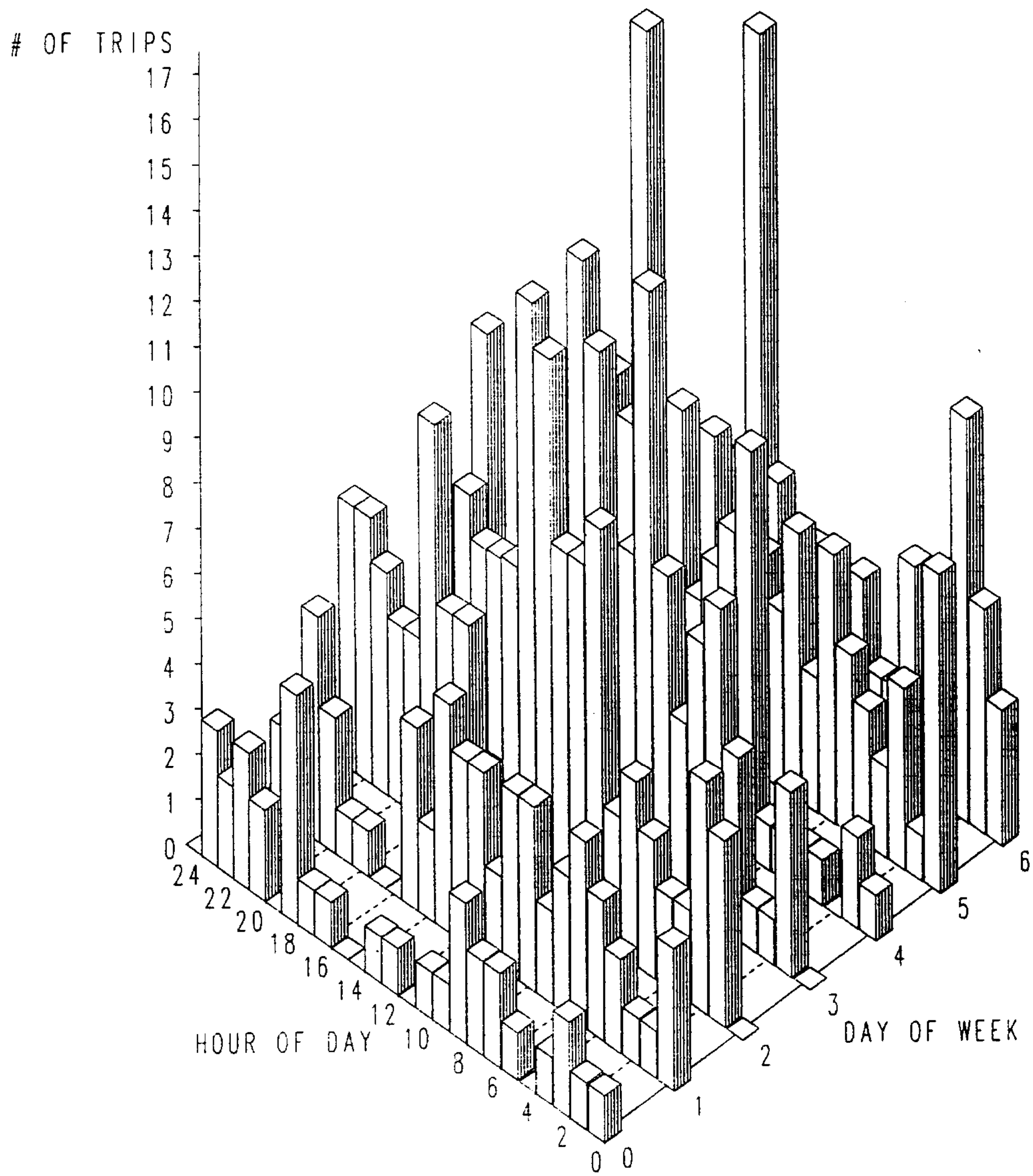


DAY OF WEEK = 0 = MONDAY, 1 = TUESDAY, ... 6 = SUNDAY

Graph 6E

PONTIAC GRAND AM CAR# 334–5

START TIME V.S. DAY OF WEEK ANALYSIS
ALL PARTICIPANTS

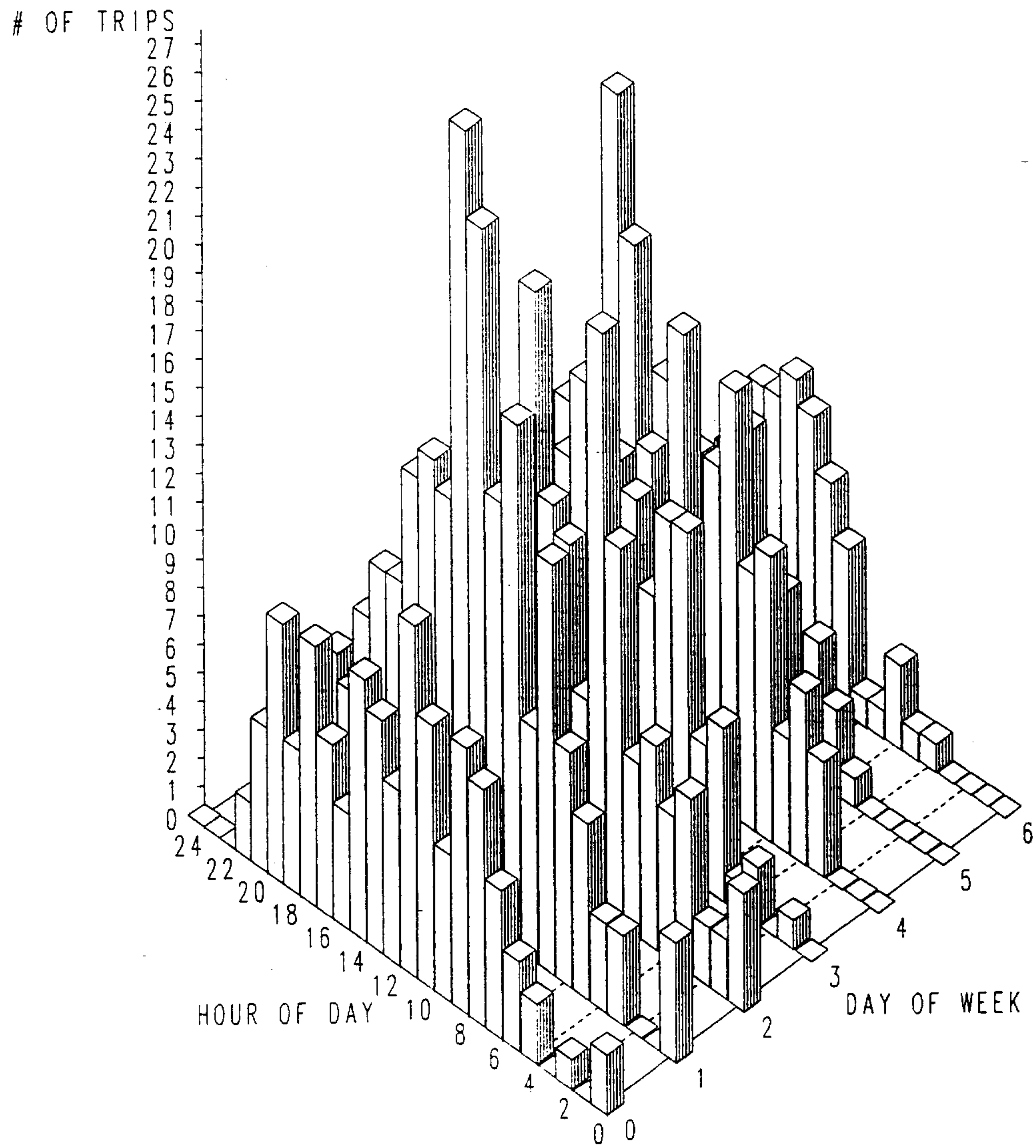


DAY OF WEEK = 0 = MONDAY. 1 = TUESDAY. ... 6 = SUNDAY

Graph 6F

HONDA ACCORD CAR# 334 – 6

START TIME V.S. DAY OF WEEK ANALYSIS
ALL PARTICIPANTS

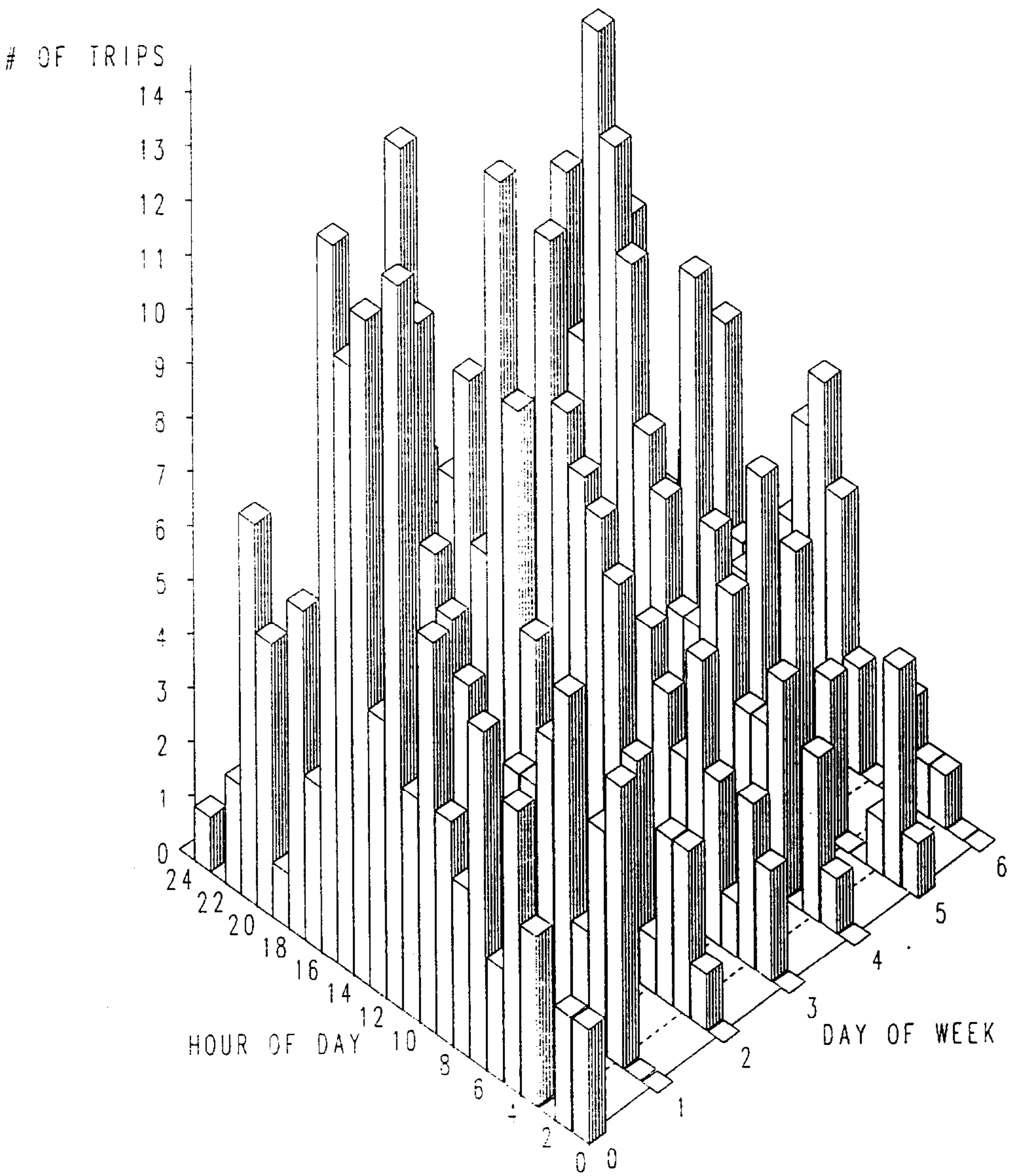


DAY OF WEEK = 0 = MONDAY. 1 = TUESDAY. ... 6 = SUNDAY

Graph 6G

TOYOTA CAMRY CAR# 334-7

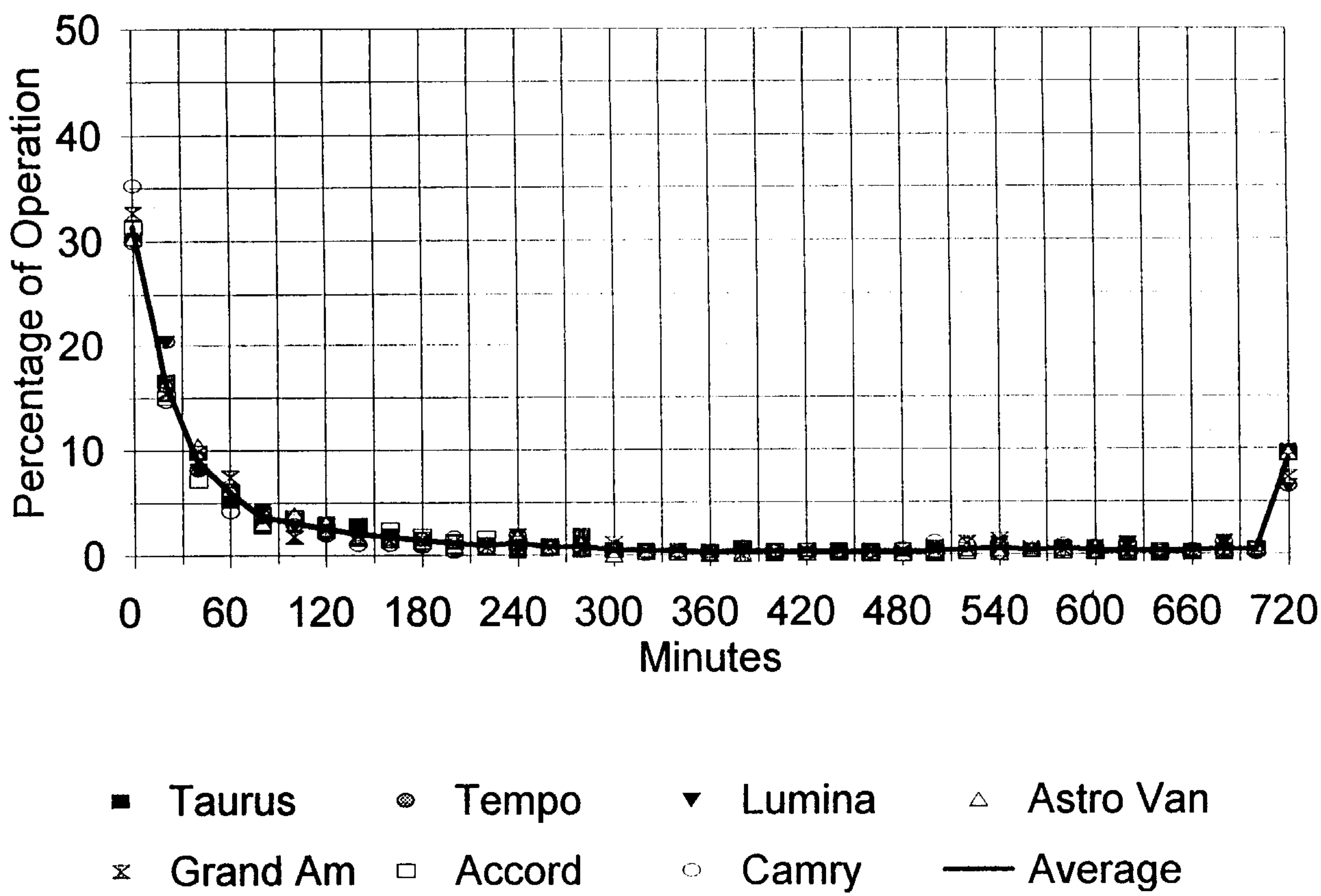
START TIME V.S. DAY OF WEEK ANALYSIS
ALL PARTICIPANTS



DAY OF WEEK = 0 = MONDAY, 1 = TUESDAY, ... 6 = SUNDAY

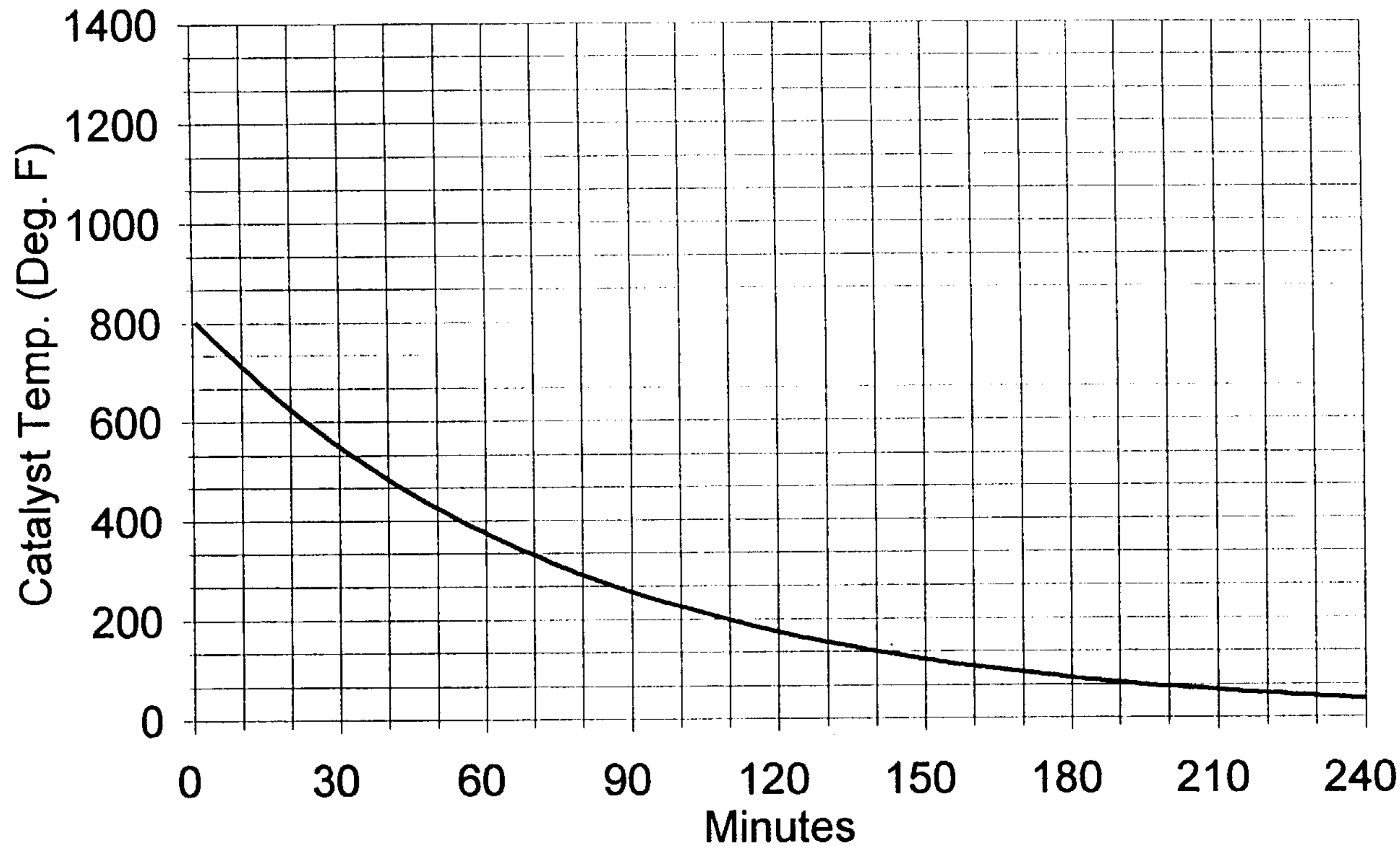
Graph 7

Soak Time



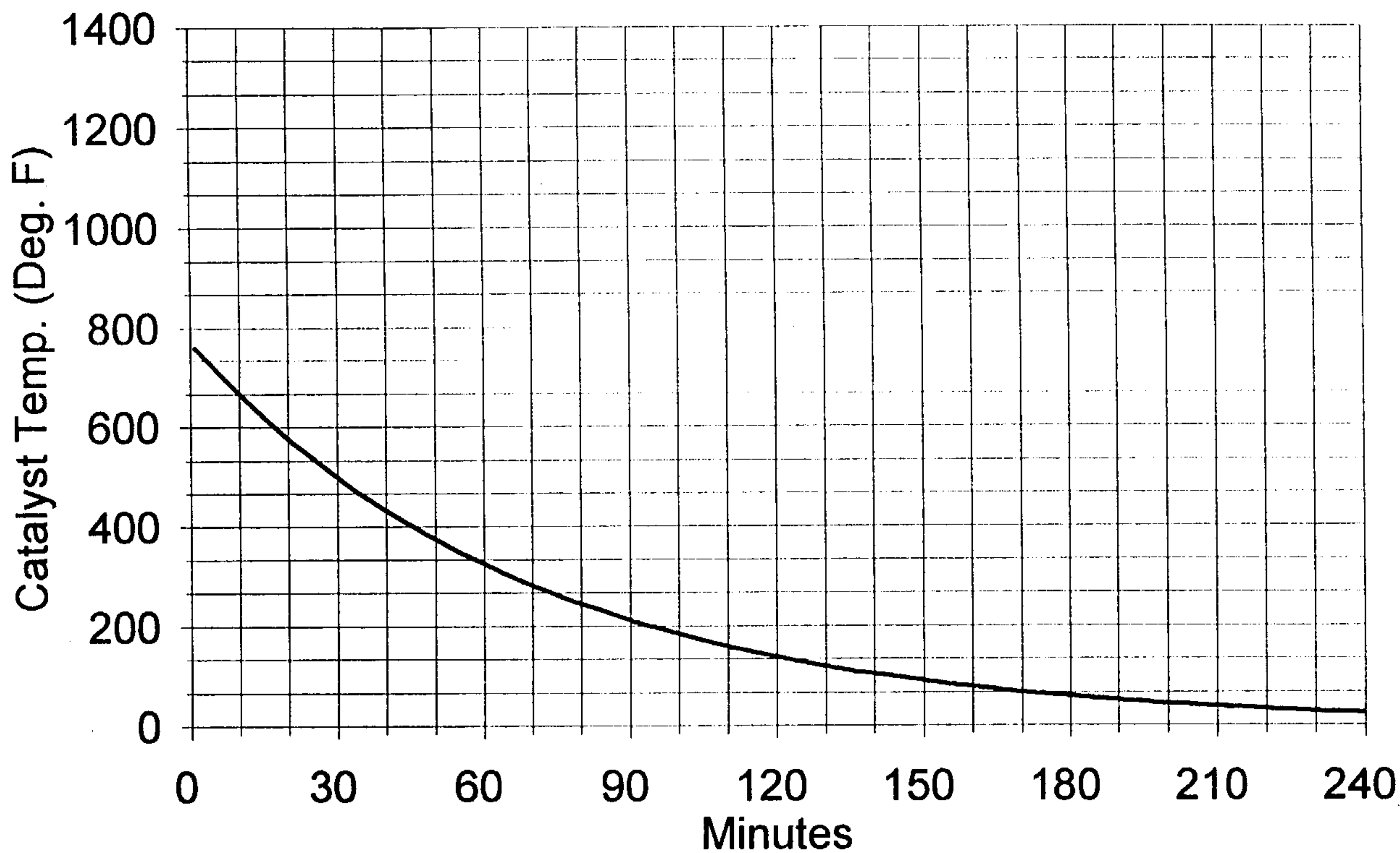
Graph 8A

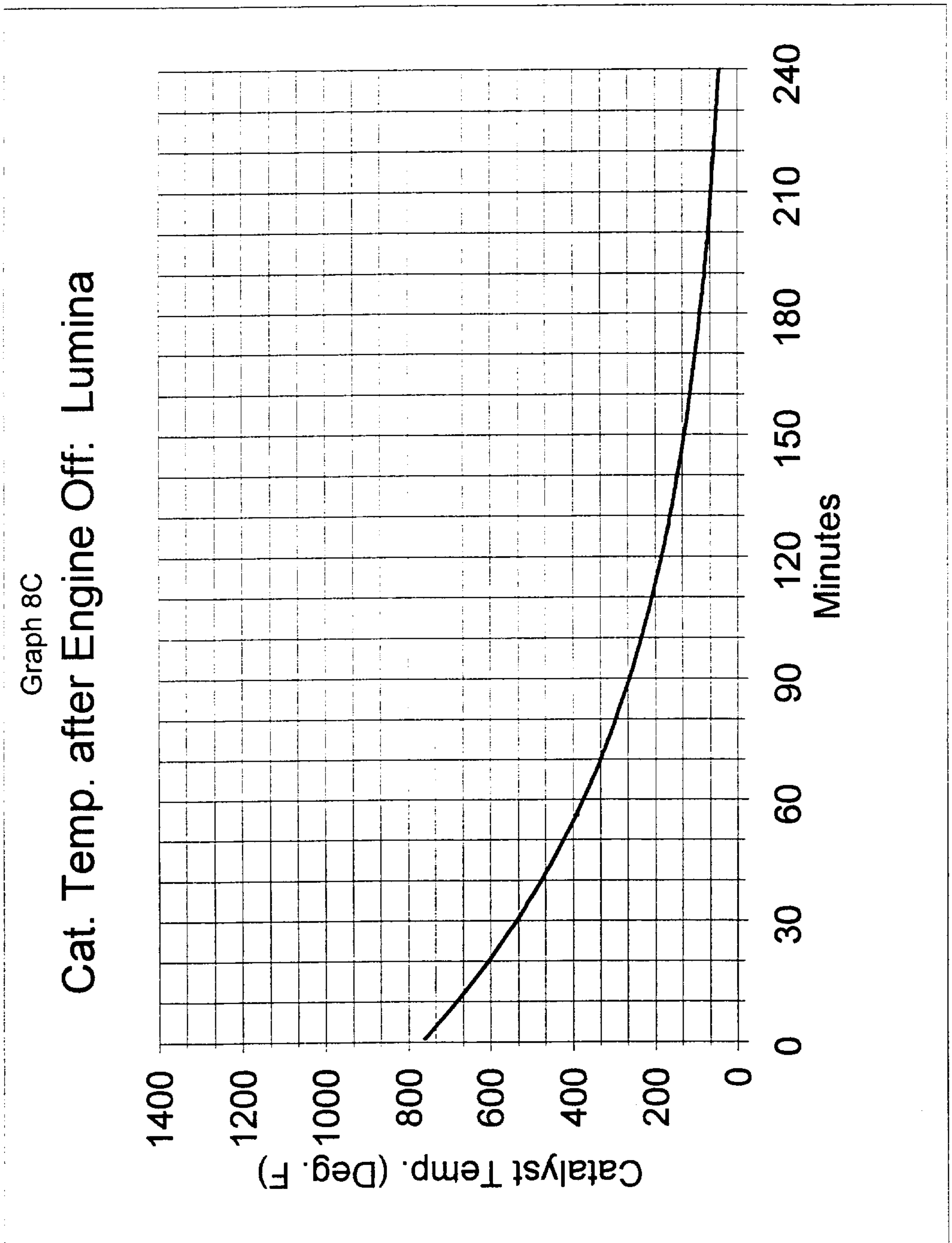
Cat. Temp. after Engine Off: Taurus



Graph 8B

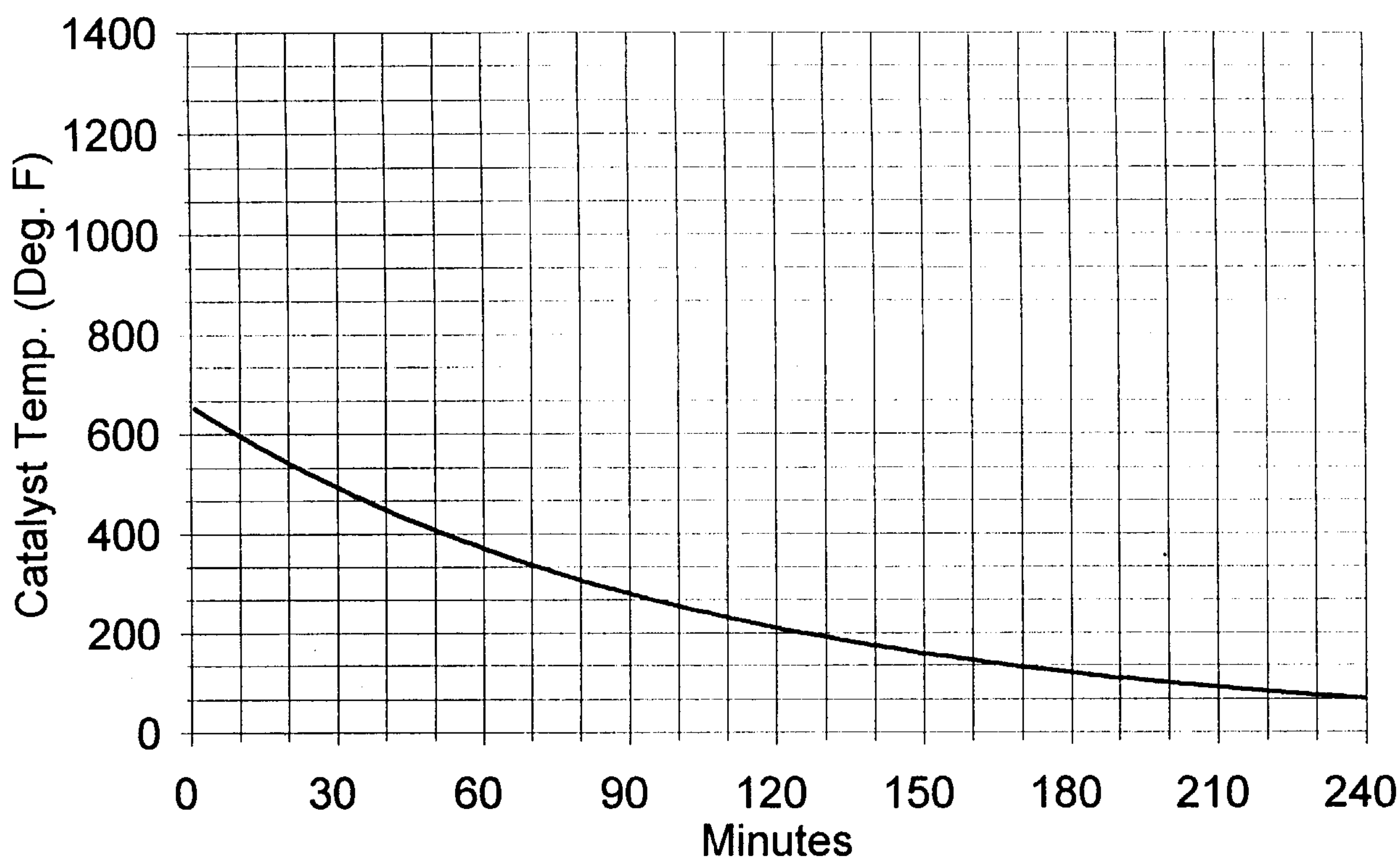
Cat. Temp. after Engine Off: Tempo




Graph 8C
Cat. Temp. after Engine Off: Lumina
Catalyst Temp. (Deg. F)
1400
1200
1000
800
600
400
200
0
0
30
60
90
120
150
180
210
240
Minutes

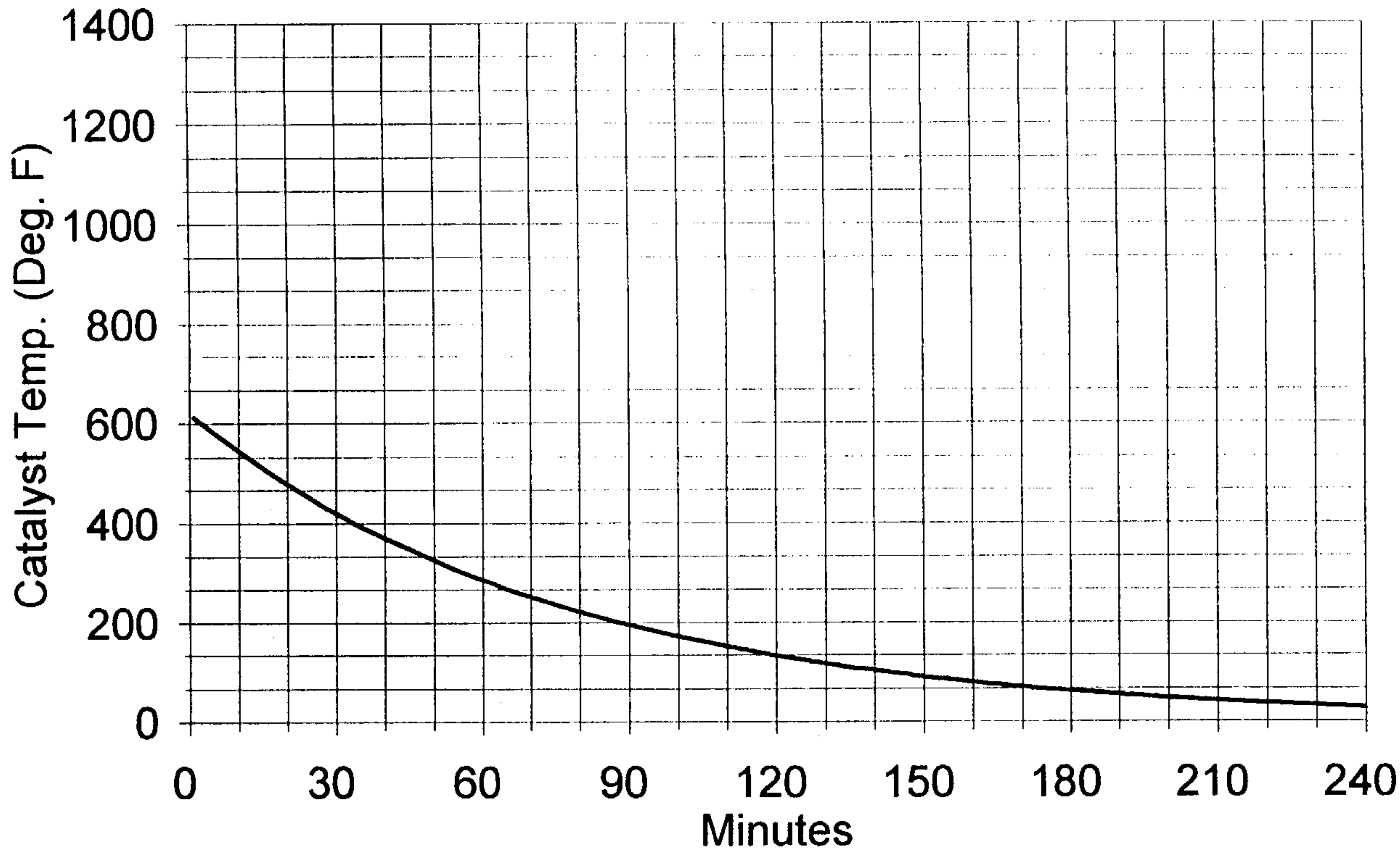
Graph 8D

Cat. Temp. after Engine Off: Astro



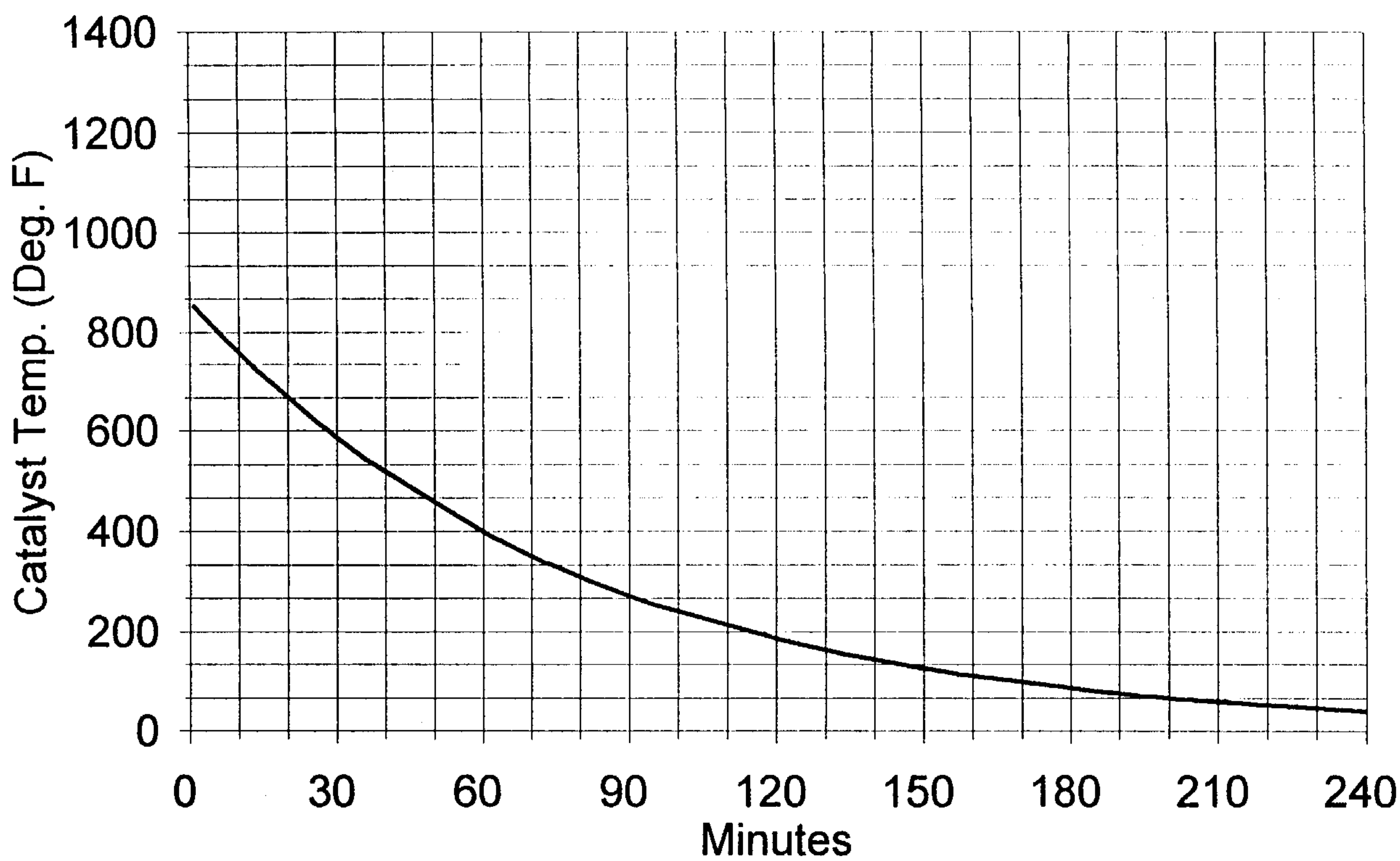
Graph 8E

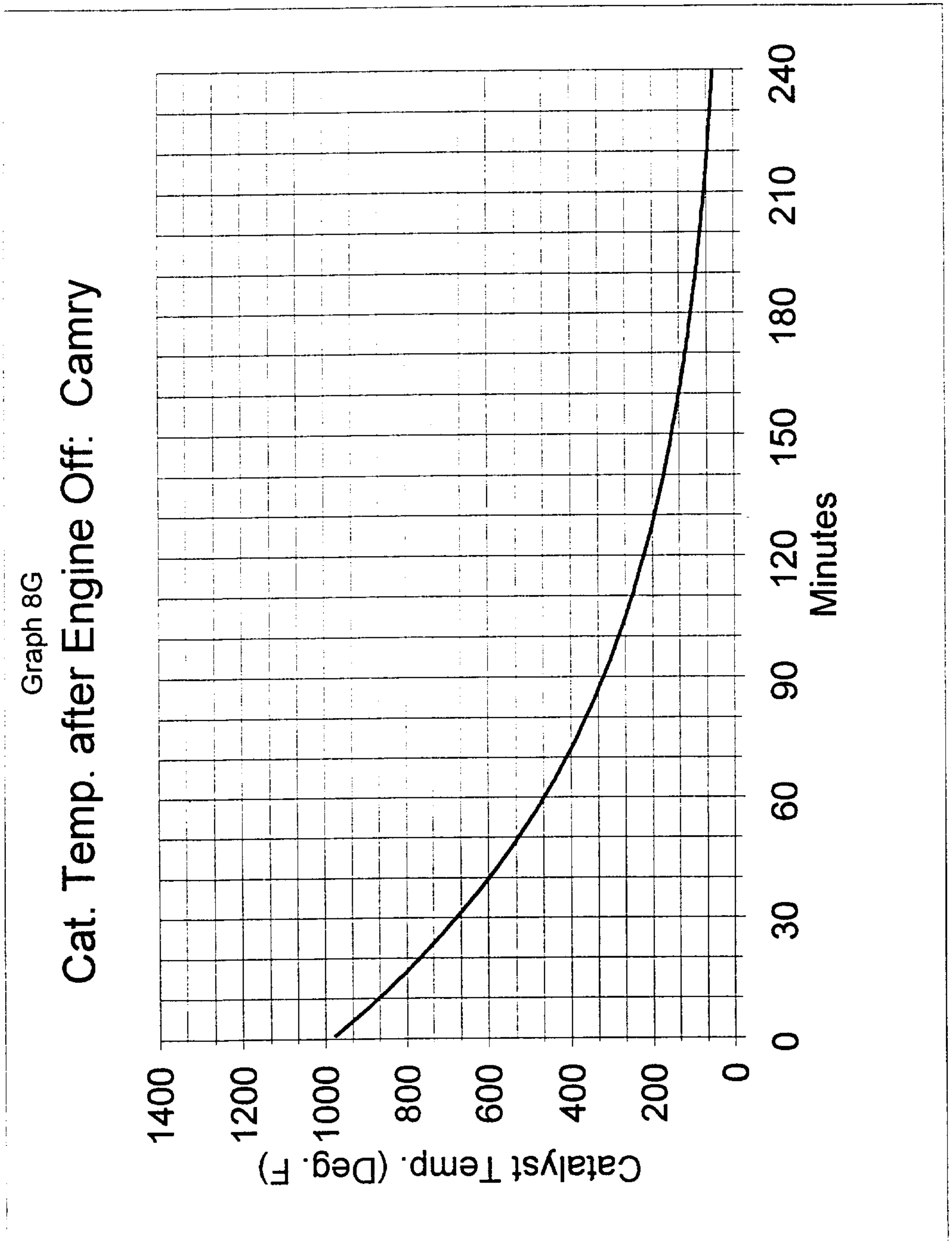
Cat. Temp. after Engine Off: Grand Am

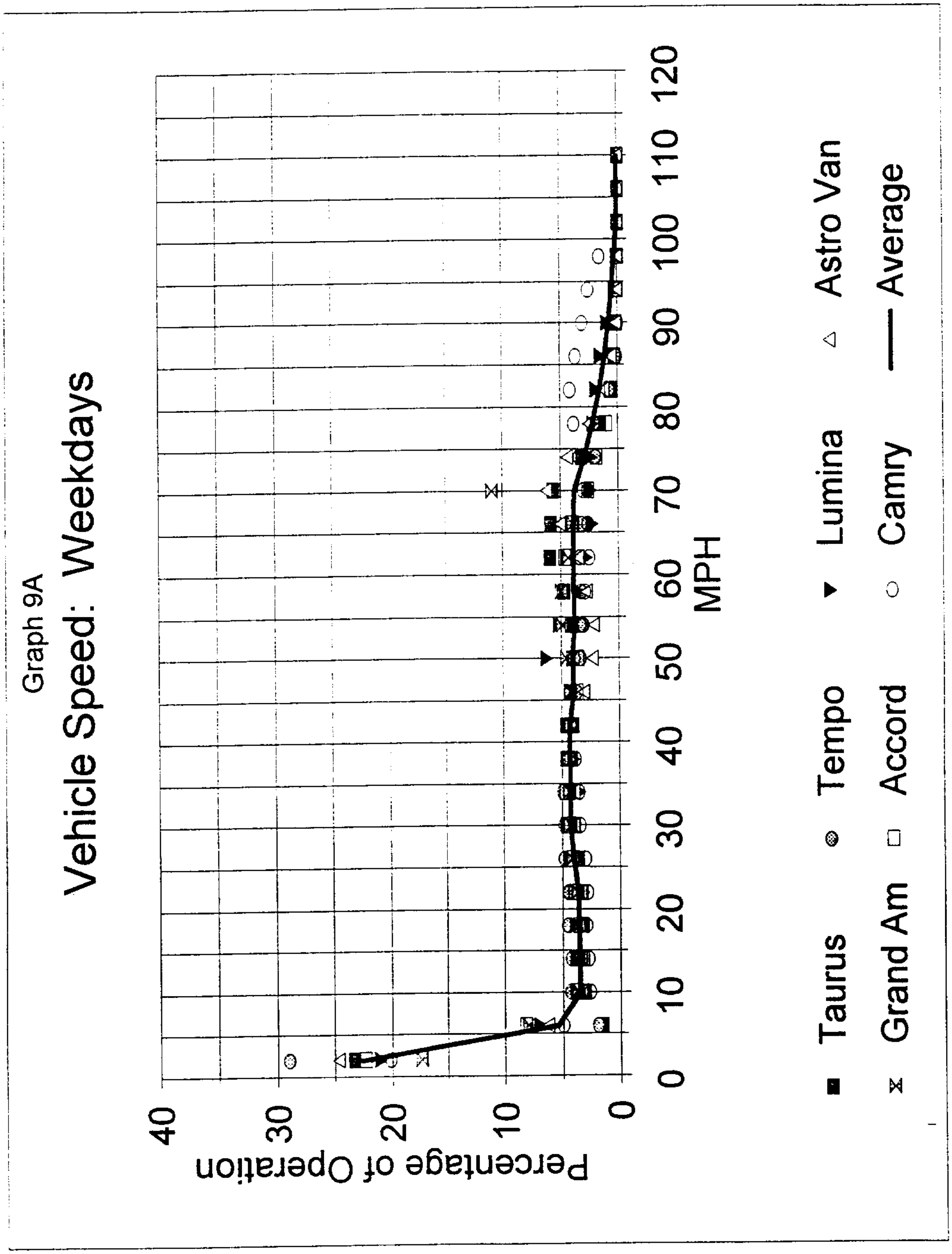


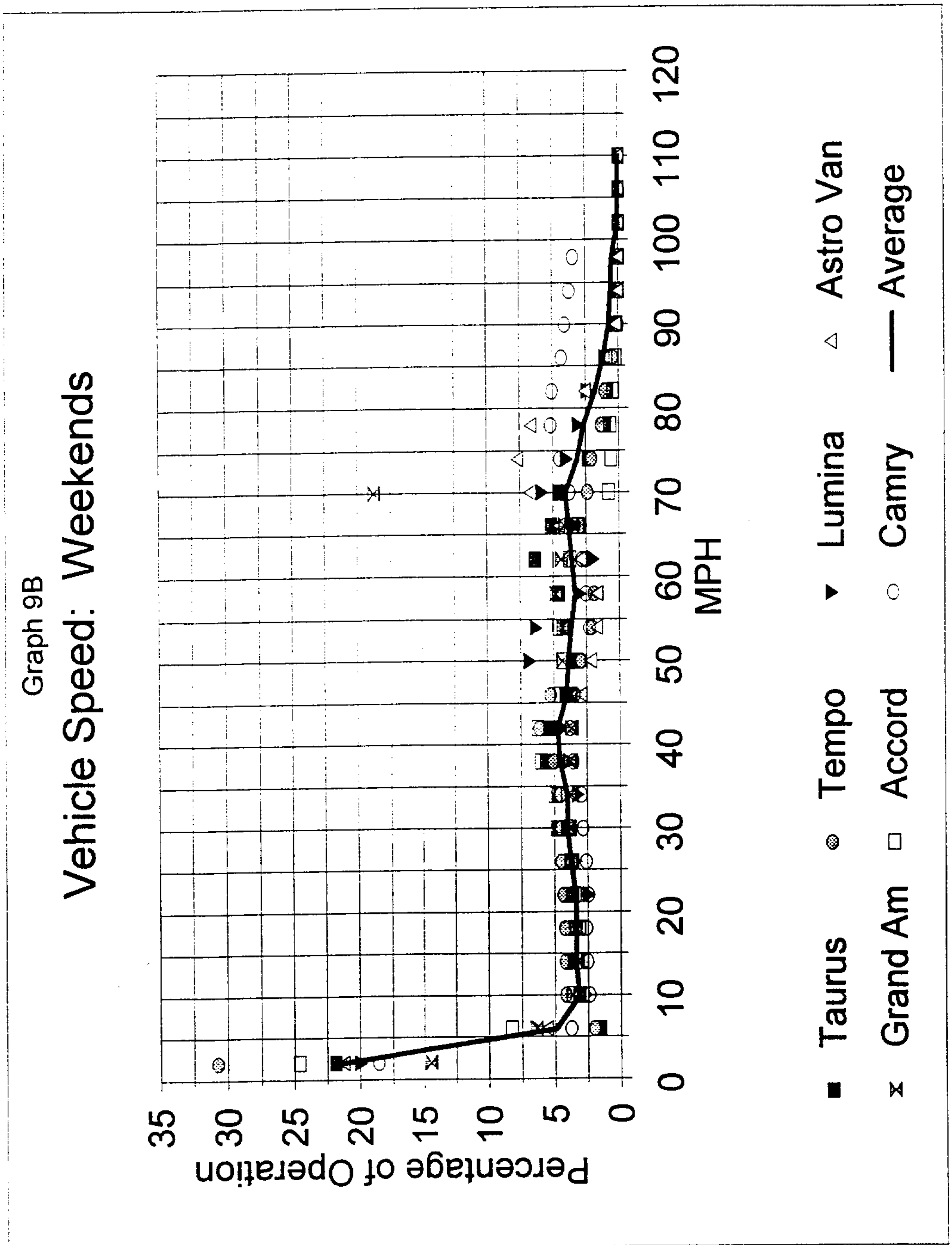
Graph 8F

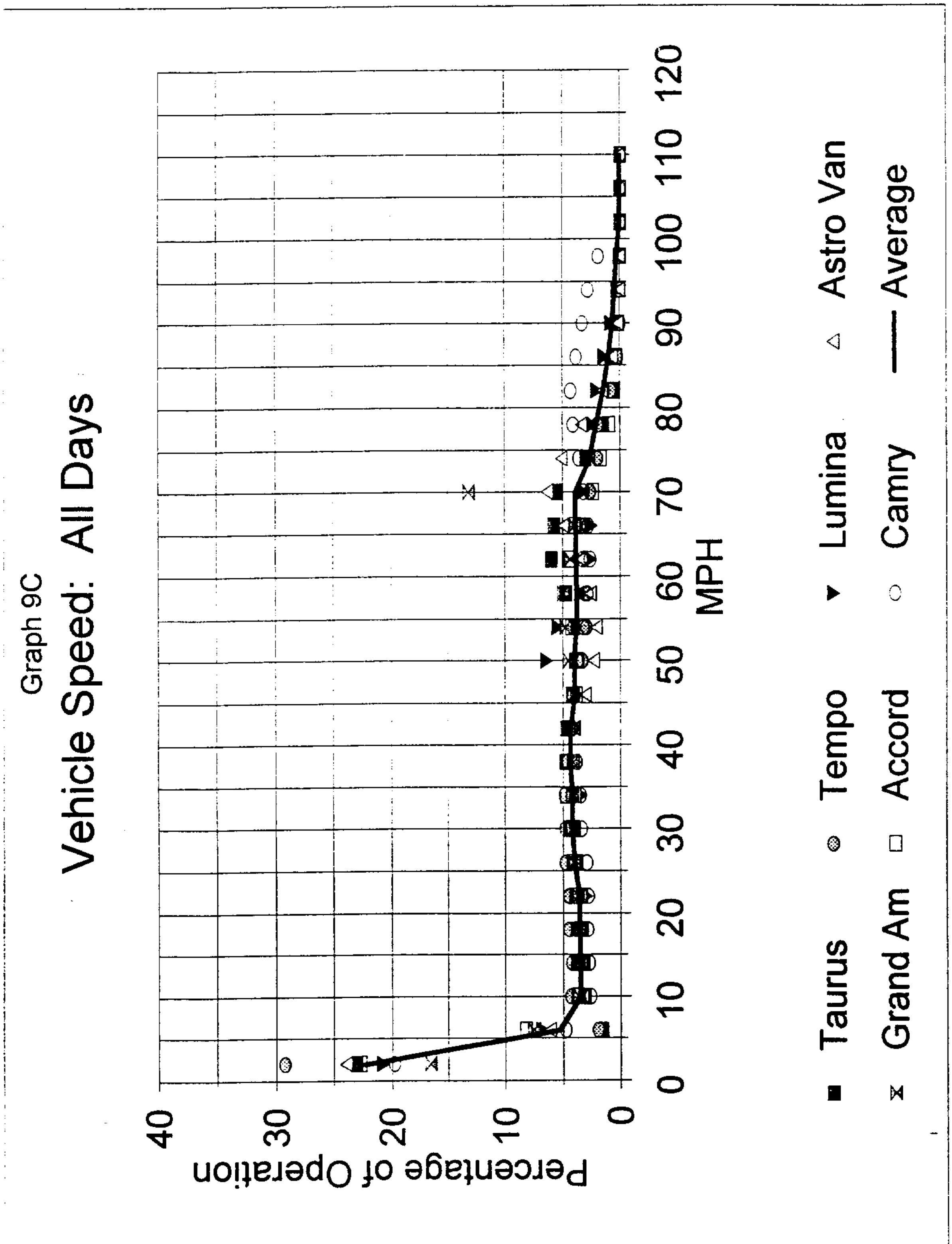
Cat. Temp. after Engine Off: Accord

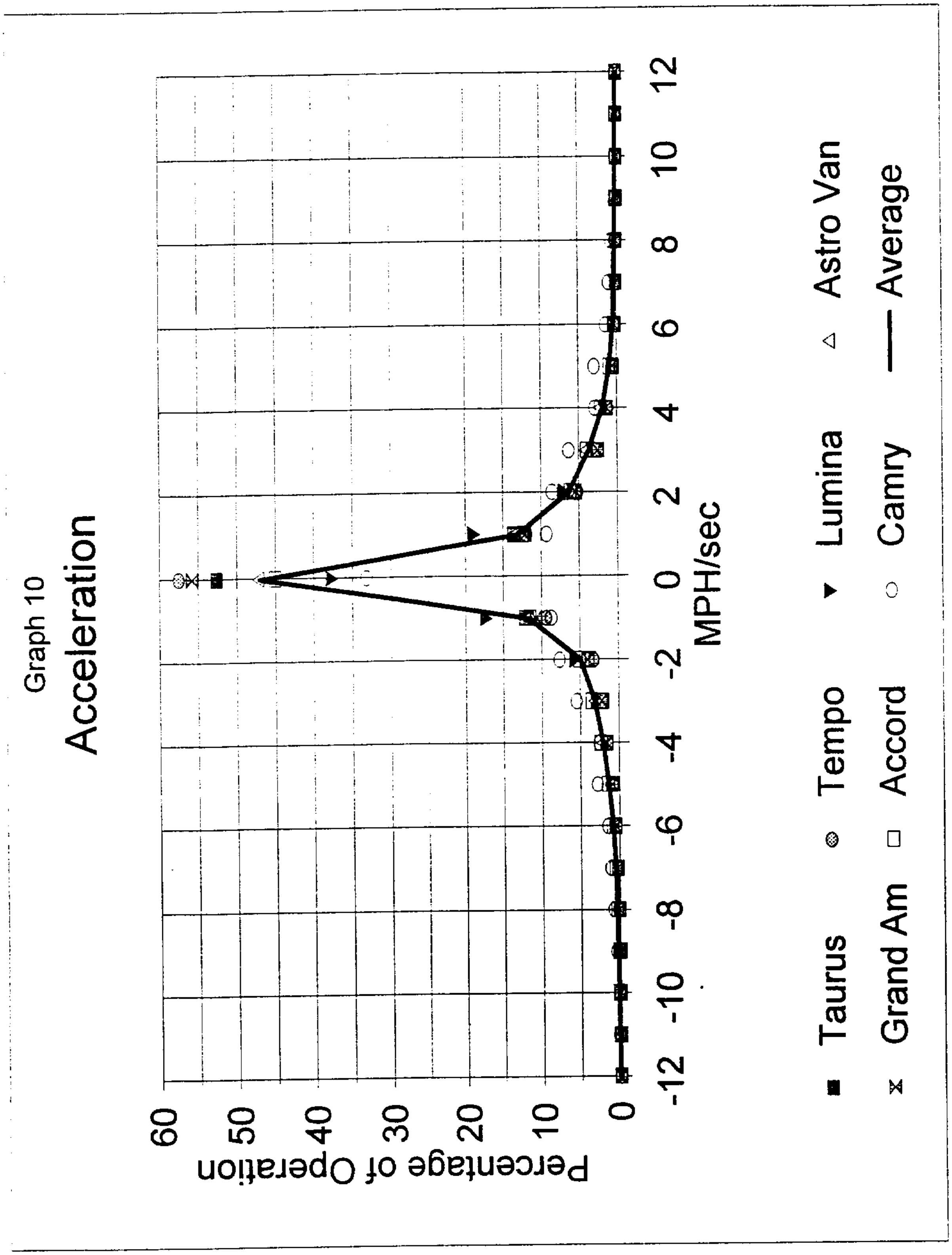



Graph 8G
Cat. Temp. after Engine Off: Camry
Catalyst Temp. (Deg. F)
1400
1200
1000
800
600
400
200
0
0
30
60
90
120
150
180
210
240
Minutes


Graph 9A
Vehicle Speed: Weekdays
Percentage of Operation
0
10
20
30
40
MPH
0
10
20
30
40
50
60
70
80
90
100
110
120
Taurus
Tempo
Lumina
Astro Van
Grand Am
Accord
Camry
Average

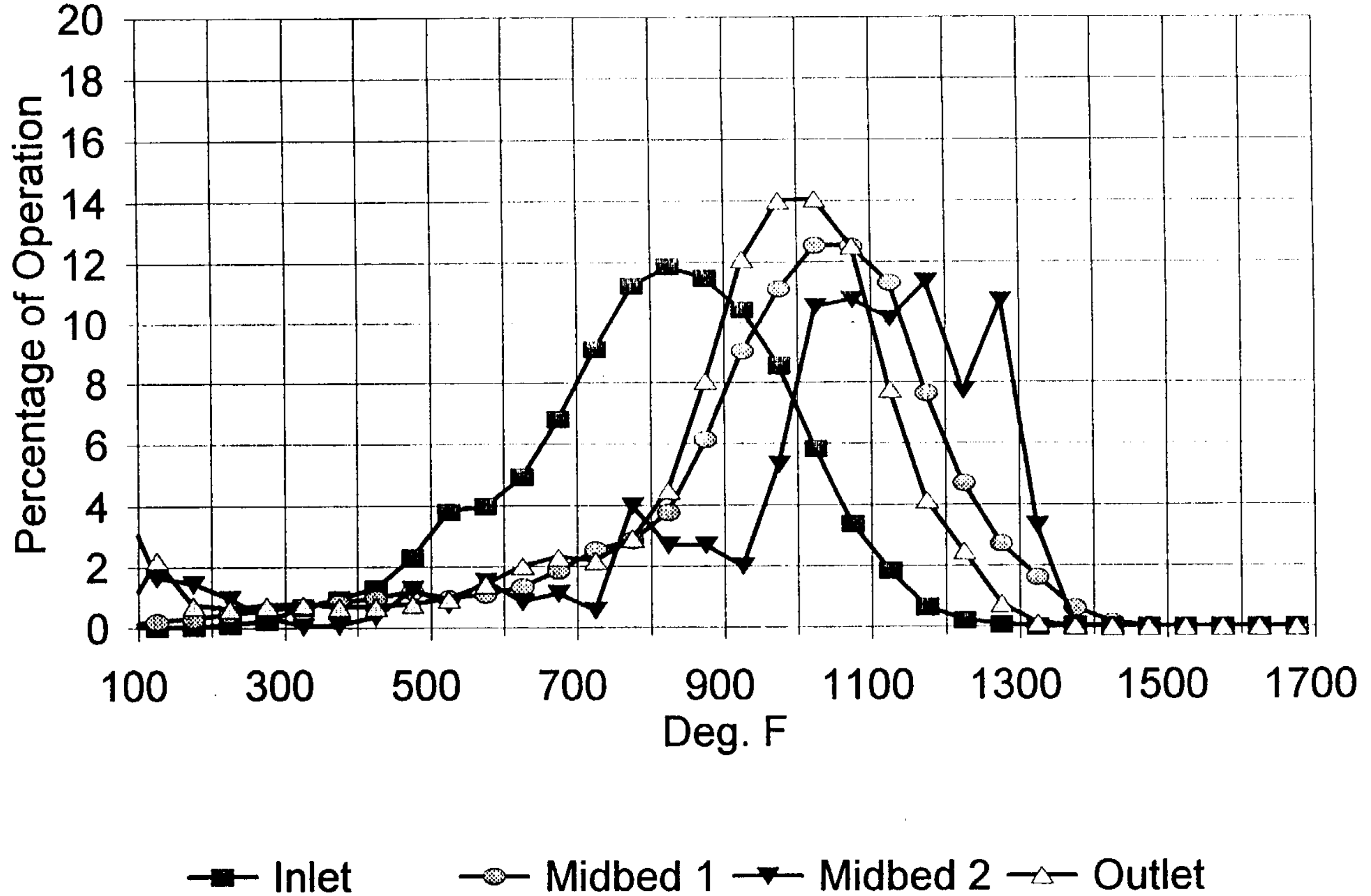

Graph 9B
Vehicle Speed: Weekends
Percentage of Operation
35
30
25
20
15
10
5
0
0
10
20
30
40
50
60
70
80
90
100
110
120
MPH
Taurus
Tempo
Lumina
Astro Van
Grand Am
Accord
Camry
Average

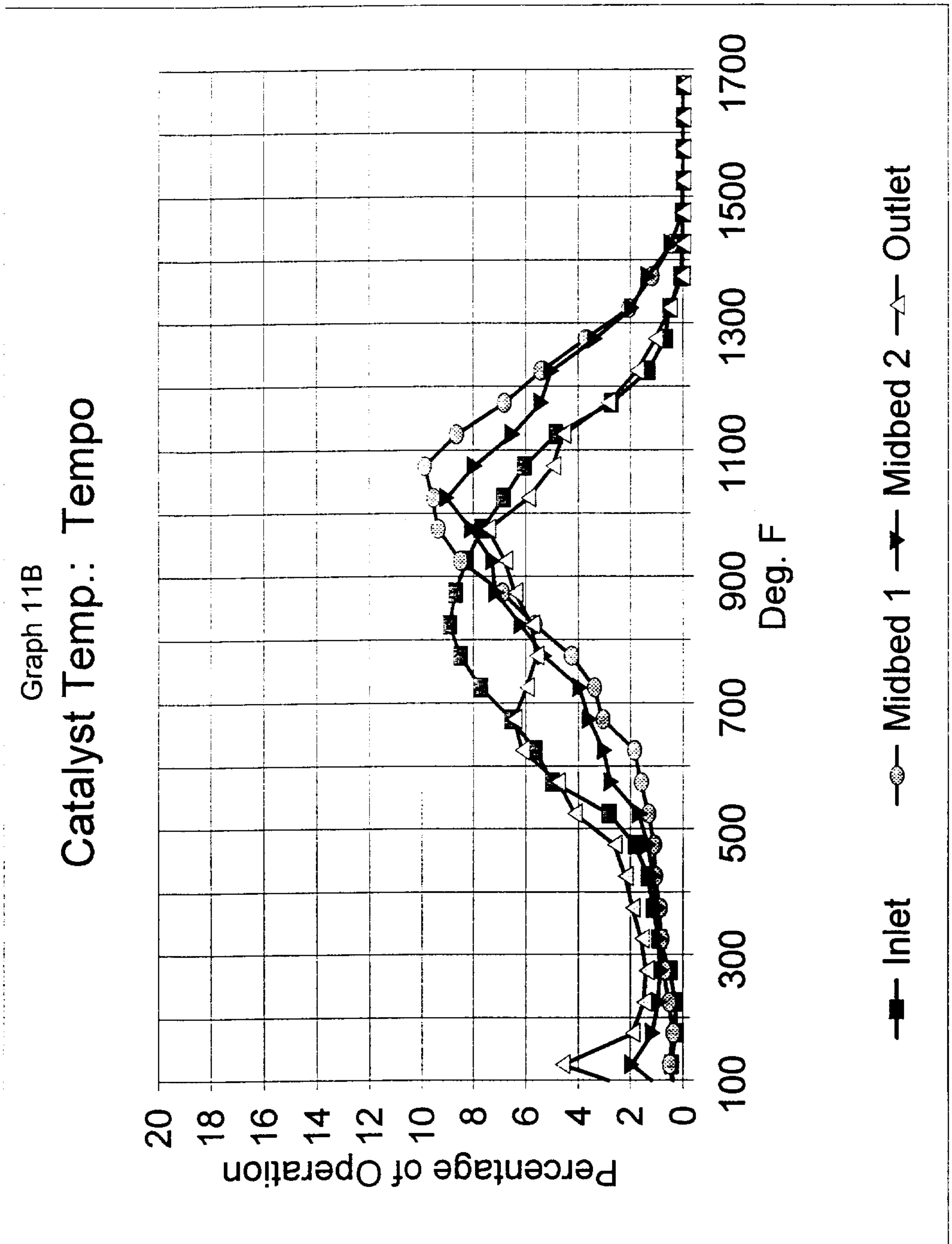

Graph 9C
Vehicle Speed: All Days
Percentage of Operation
MPH
0
10
20
30
40
0
10
20
30
40
50
60
70
80
90
100
110
120
Taurus
Tempo
Lumina
Astro Van
Grand Am
Accord
Camry
Average


Graph 10
Acceleration
Percentage of Operation
60
50
40
30
20
10
0
-12
-10
-8
-6
-4
-2
0
2
4
6
8
10
12
MPH/sec
Taurus
Tempo
Lumina
Astro Van
Grand Am
Accord
Camry
Average

Graph 11A

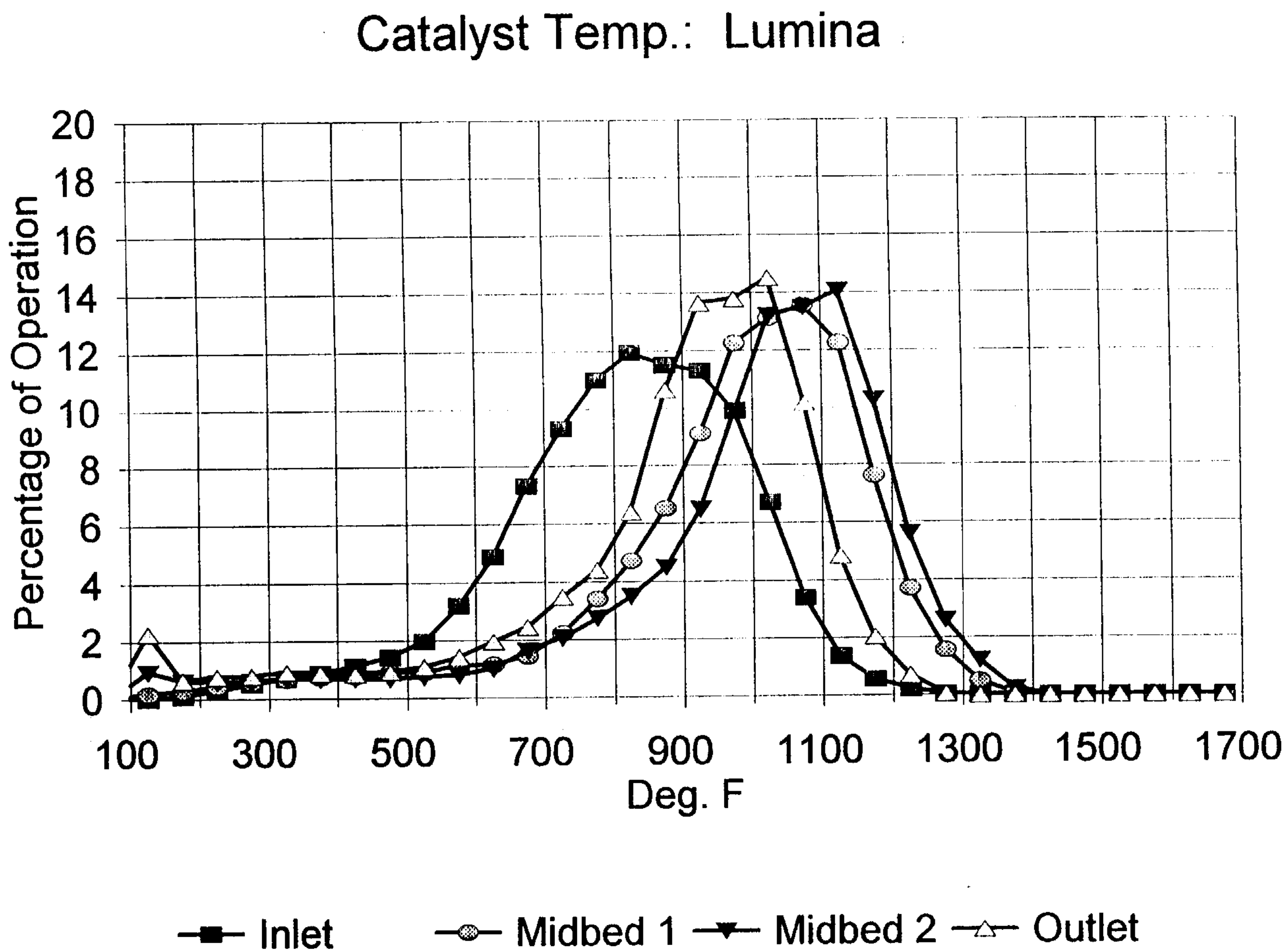
Catalyst Temp.: Taurus





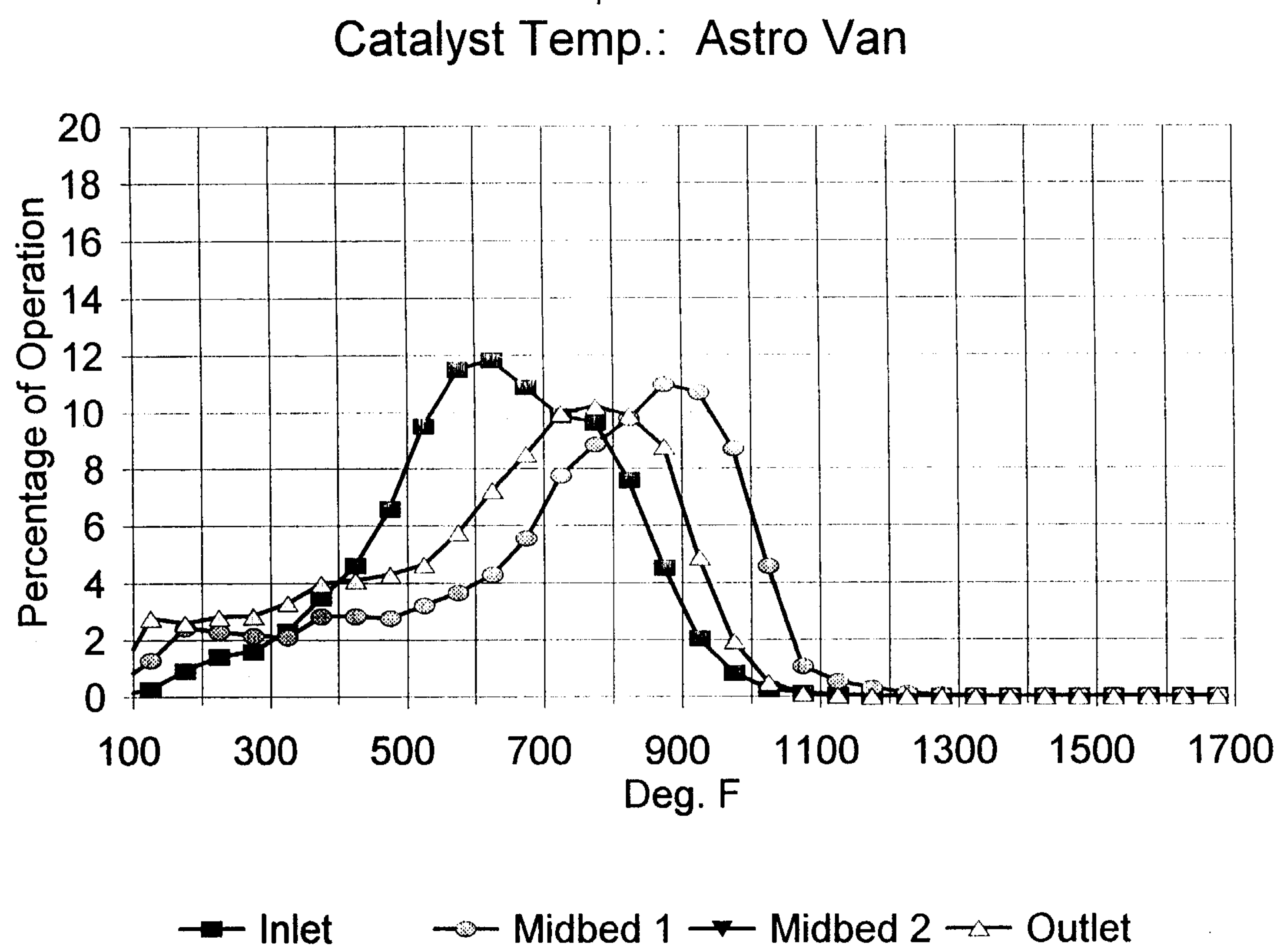
Graph 11B
Catalyst Temp.: Tempo
Percentage of Operation
20
18
16
14
12
10
8
6
4
2
0
100
300
500
700
900
1100
1300
1500
1700
Deg. F
Inlet
Midbed 1
Midbed 2
Outlet

Graph 11C



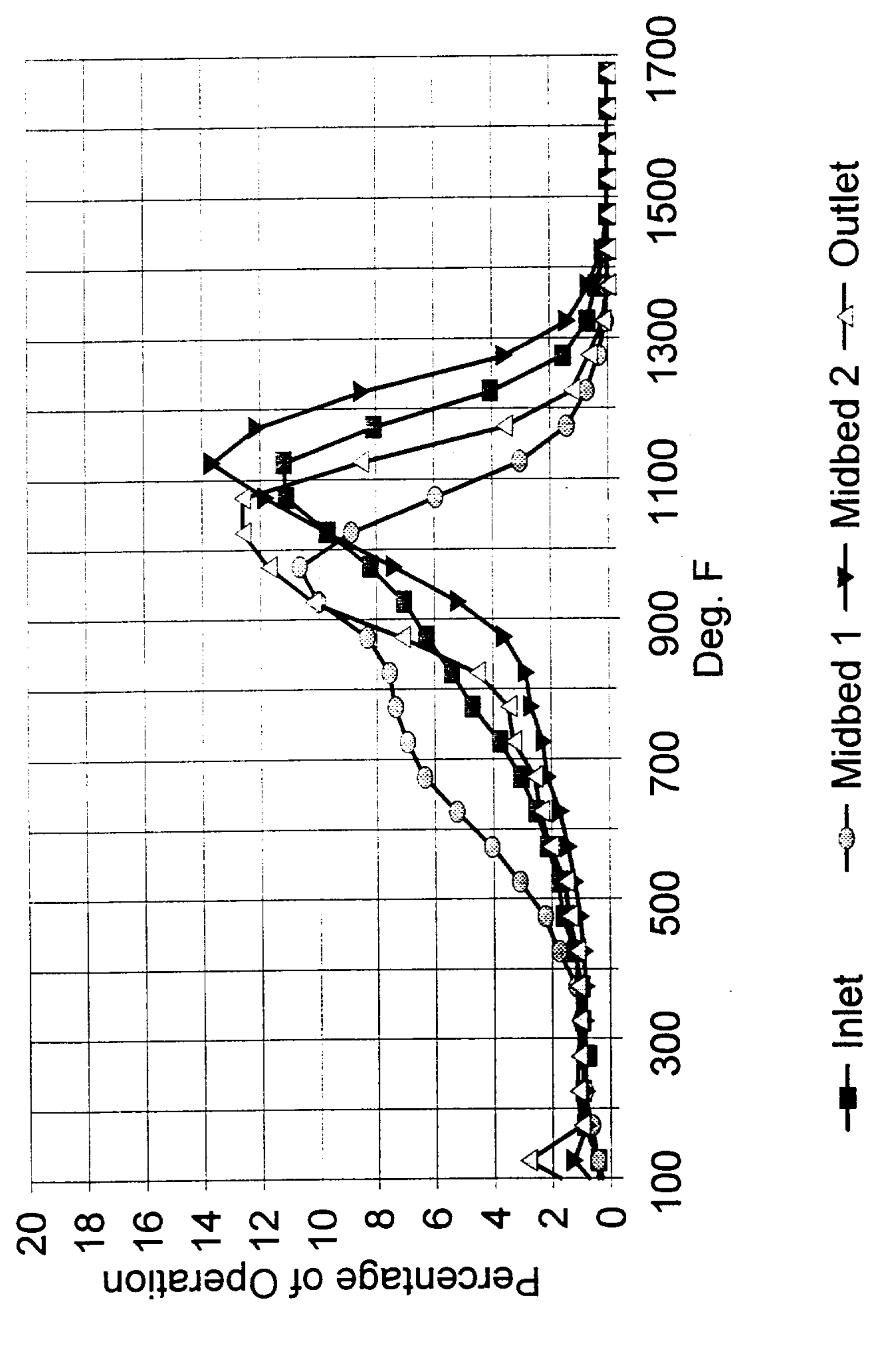
Catalyst Temp.: Lumina
Percentage of Operation
20
18
16
14
12
10
8
6
4
2
0
100
300
500
700
900
1100
1300
1500
1700
Deg. F
Inlet
Midbed 1
Midbed 2
Outlet

Graph 11D

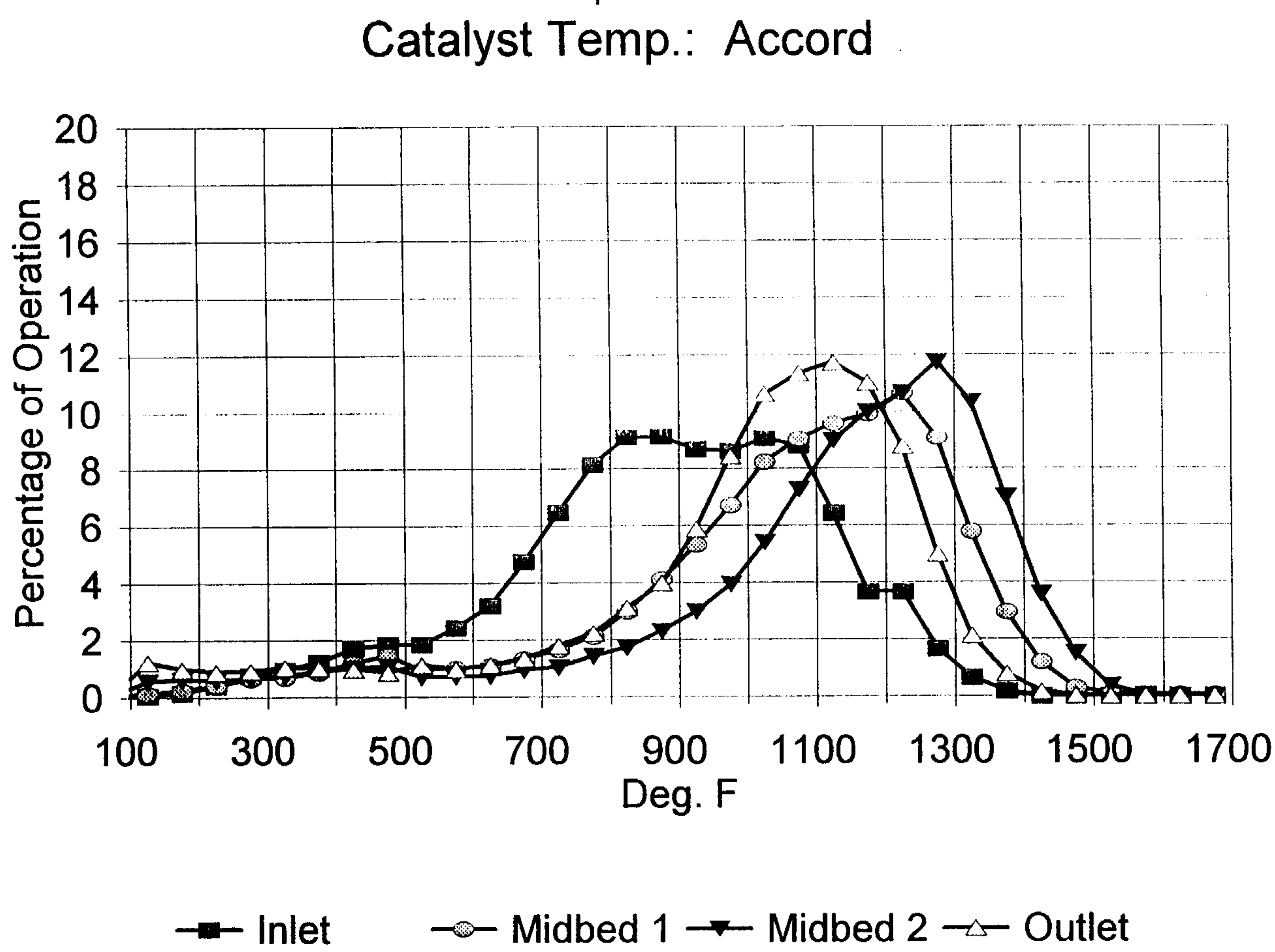

Catalyst Temp.: Astro Van
Percentage of Operation
20
18
16
14
12
10
8
6
4
2
0
100
300
500
700
900
1100
1300
1500
1700
Deg. F
Inlet
Midbed 1
Midbed 2
Outlet

Graph 11E

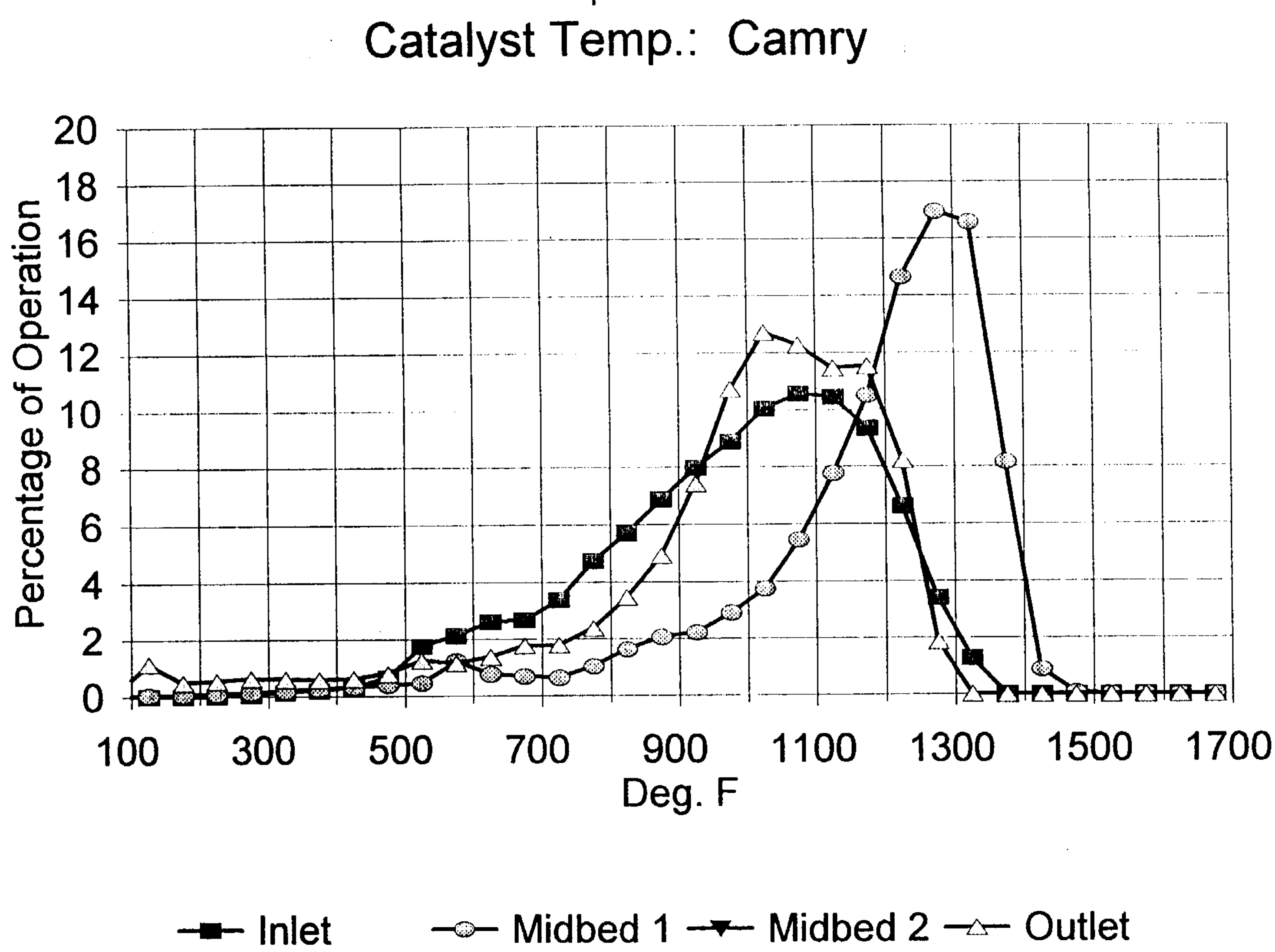
Catalyst Temp.: Grand Am



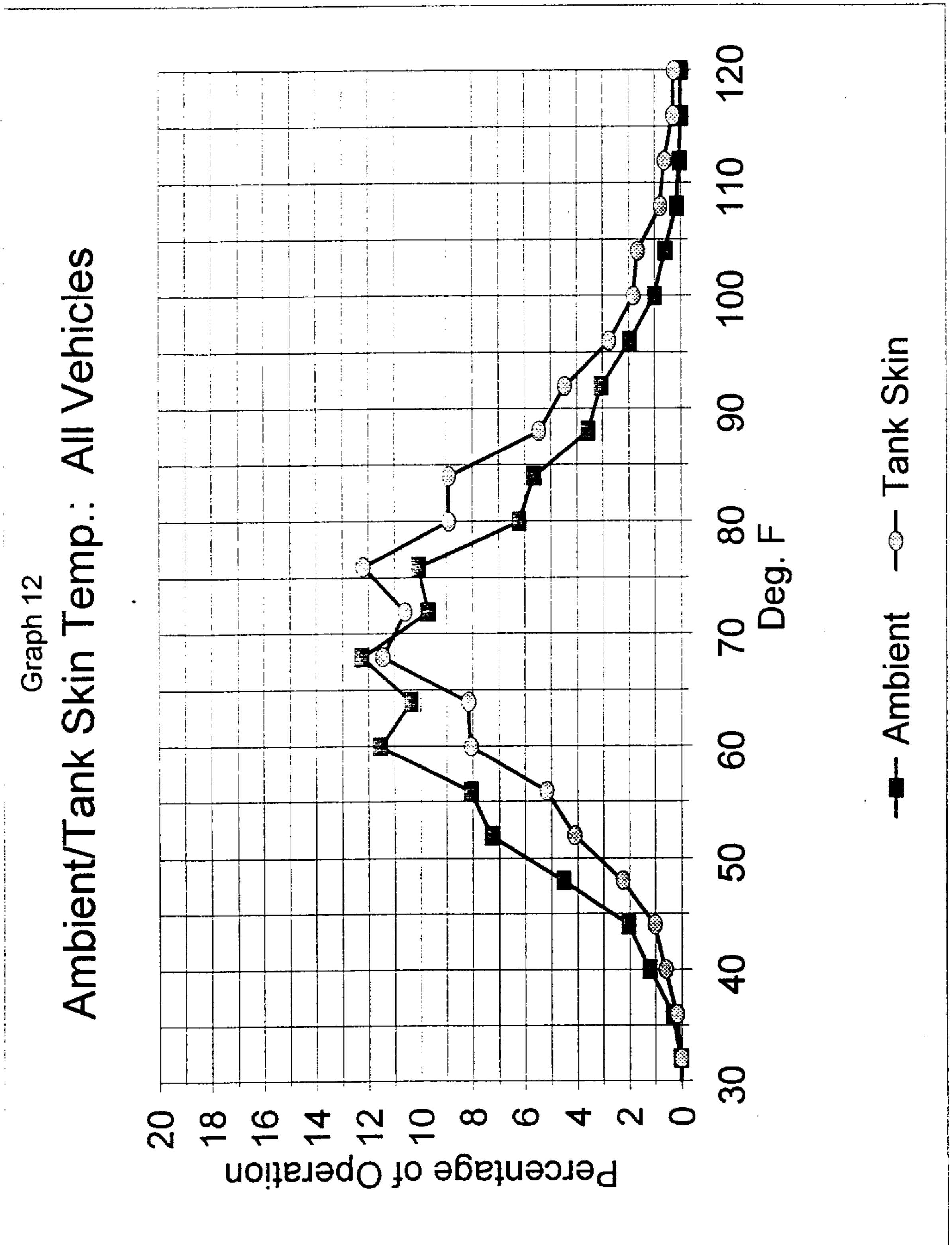
Graph 11F


Catalyst Temp.: Accord
Percentage of Operation
20
18
16
14
12
10
8
6
4
2
0
100
300
500
700
900
1100
1300
1500
1700
Deg. F
Inlet
Midbed 1
Midbed 2
Outlet

Graph 11G

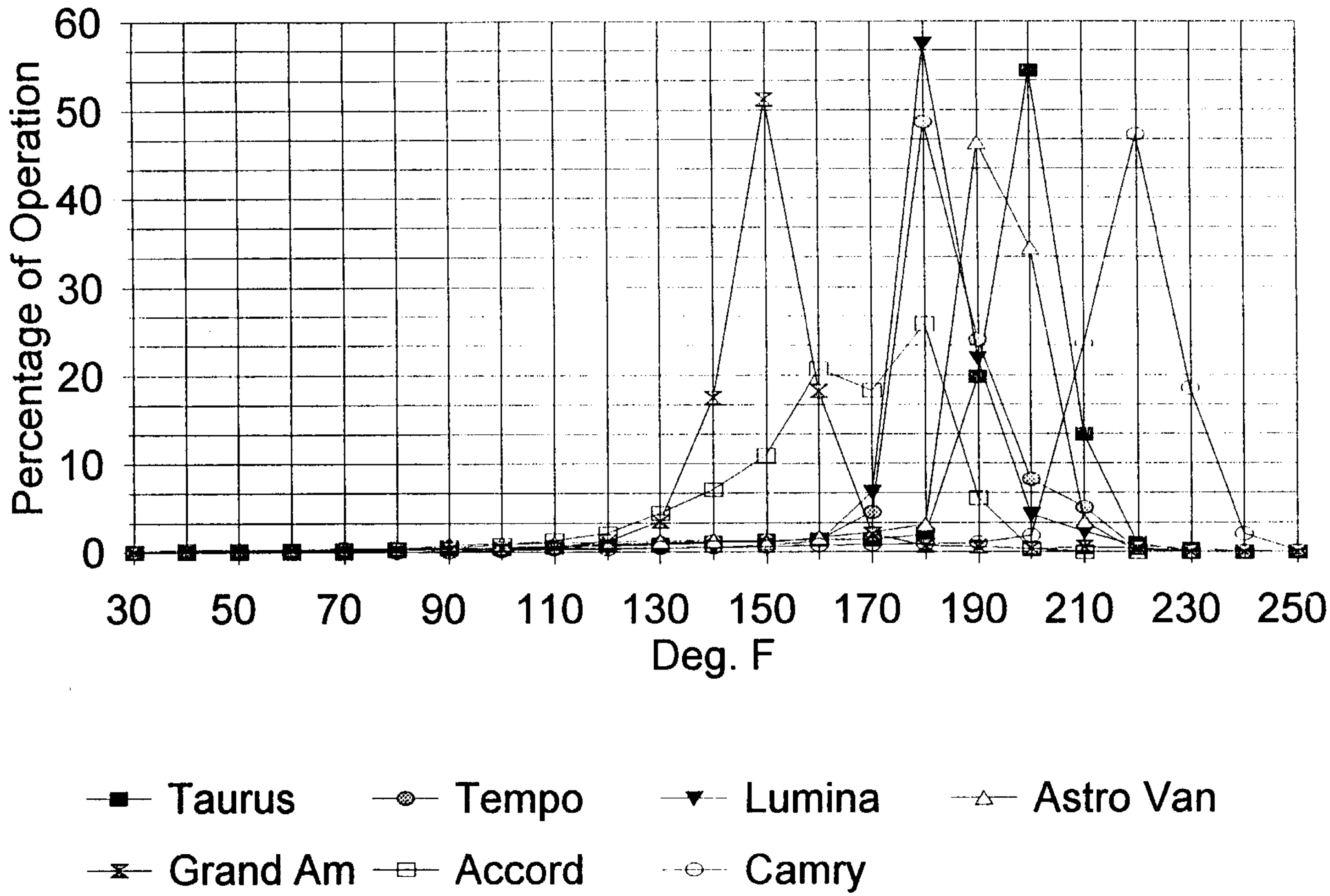


Catalyst Temp.: Camry
Percentage of Operation
20
18
16
14
12
10
8
6
4
2
0
100
300
500
700
900
1100
1300
1500
1700
Deg. F
Inlet
Midbed 1
Midbed 2
Outlet


Graph 12
Ambient/Tank Skin Temp.: All Vehicles
Percentage of Operation
20
18
16
14
12
10
8
6
4
2
0
30
40
50
60
70
80
90
100
110
120
Deg. F
Ambient
Tank Skin

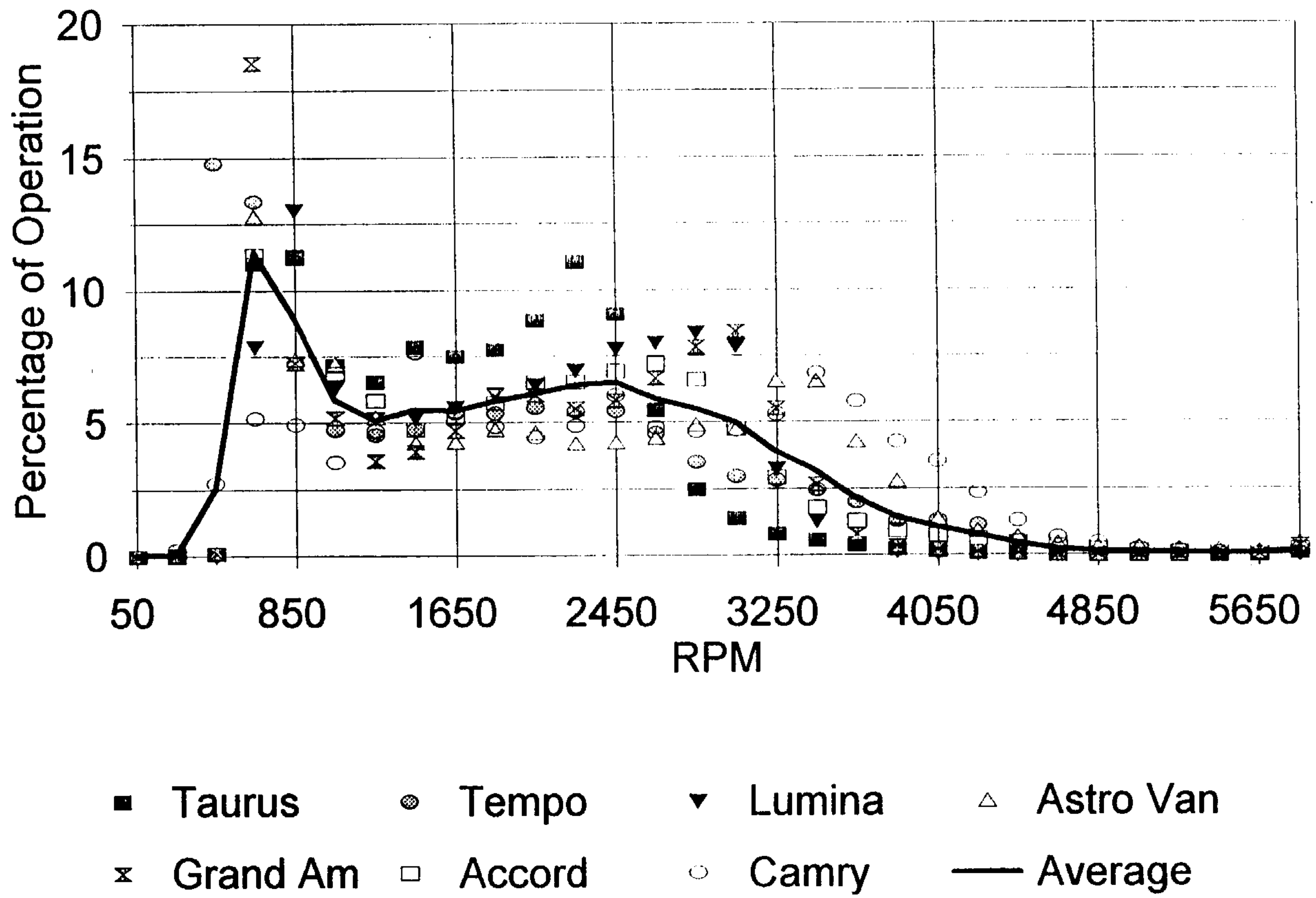
Graph 13

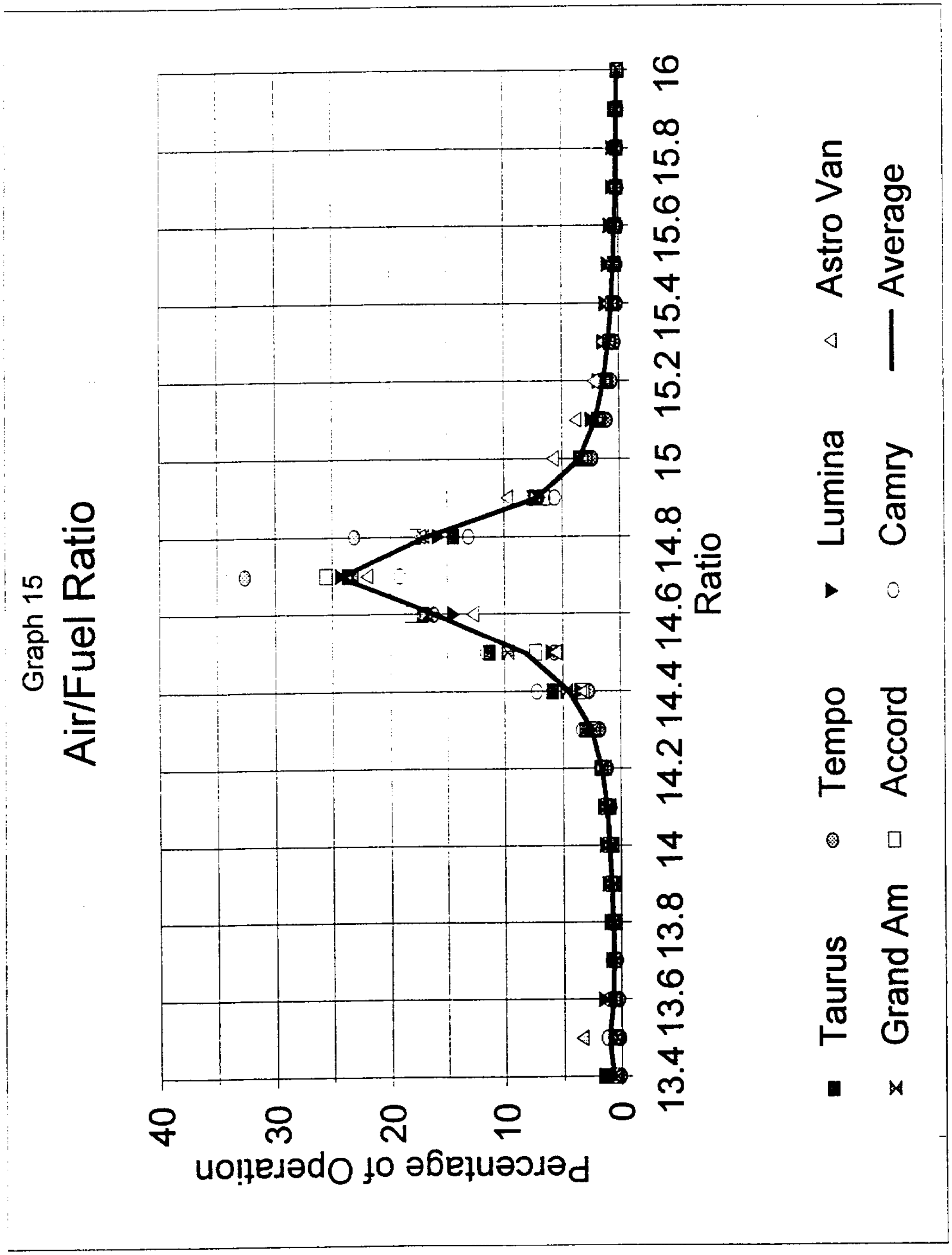
Engine Coolant Temp.: All Vehicles



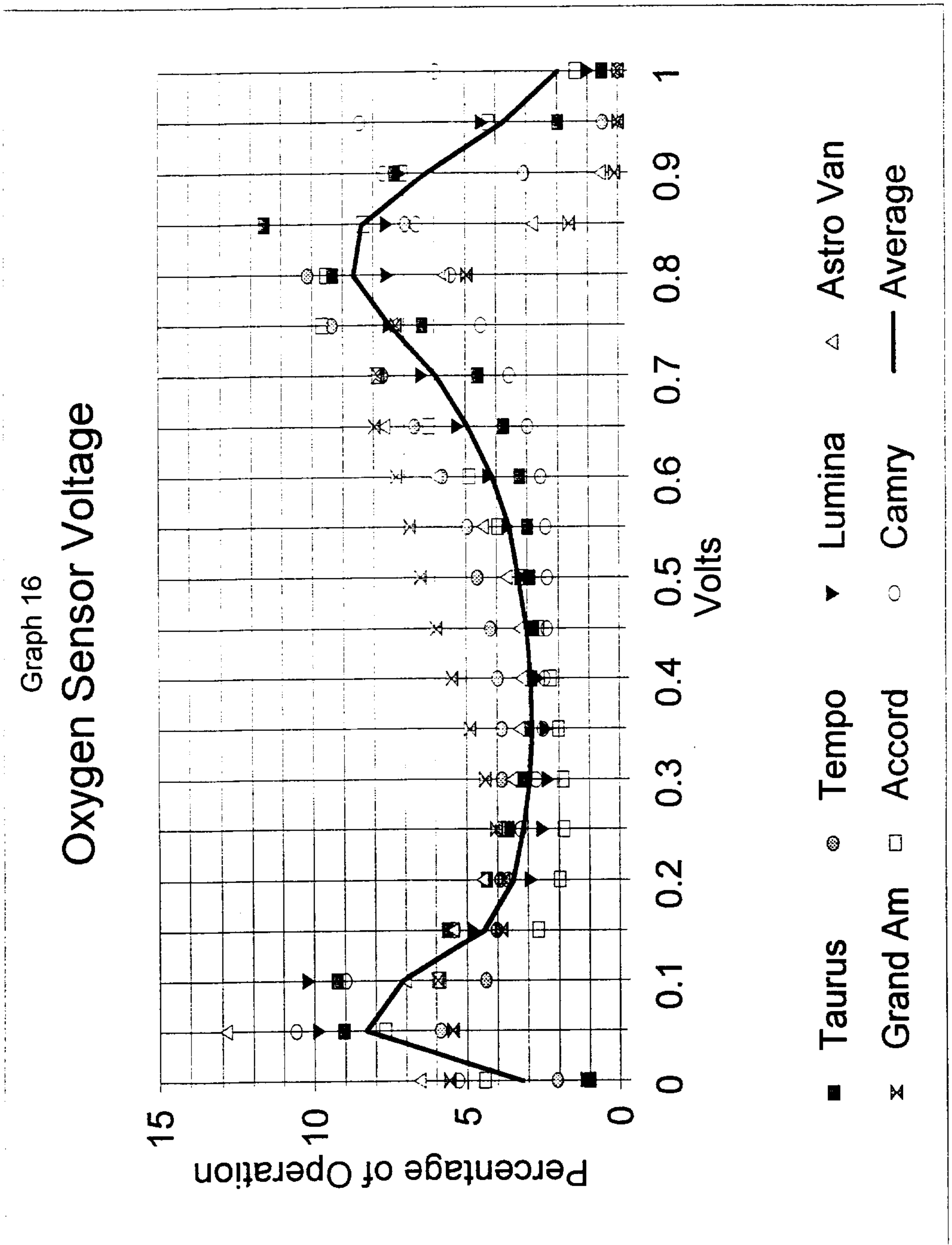
Graph 14

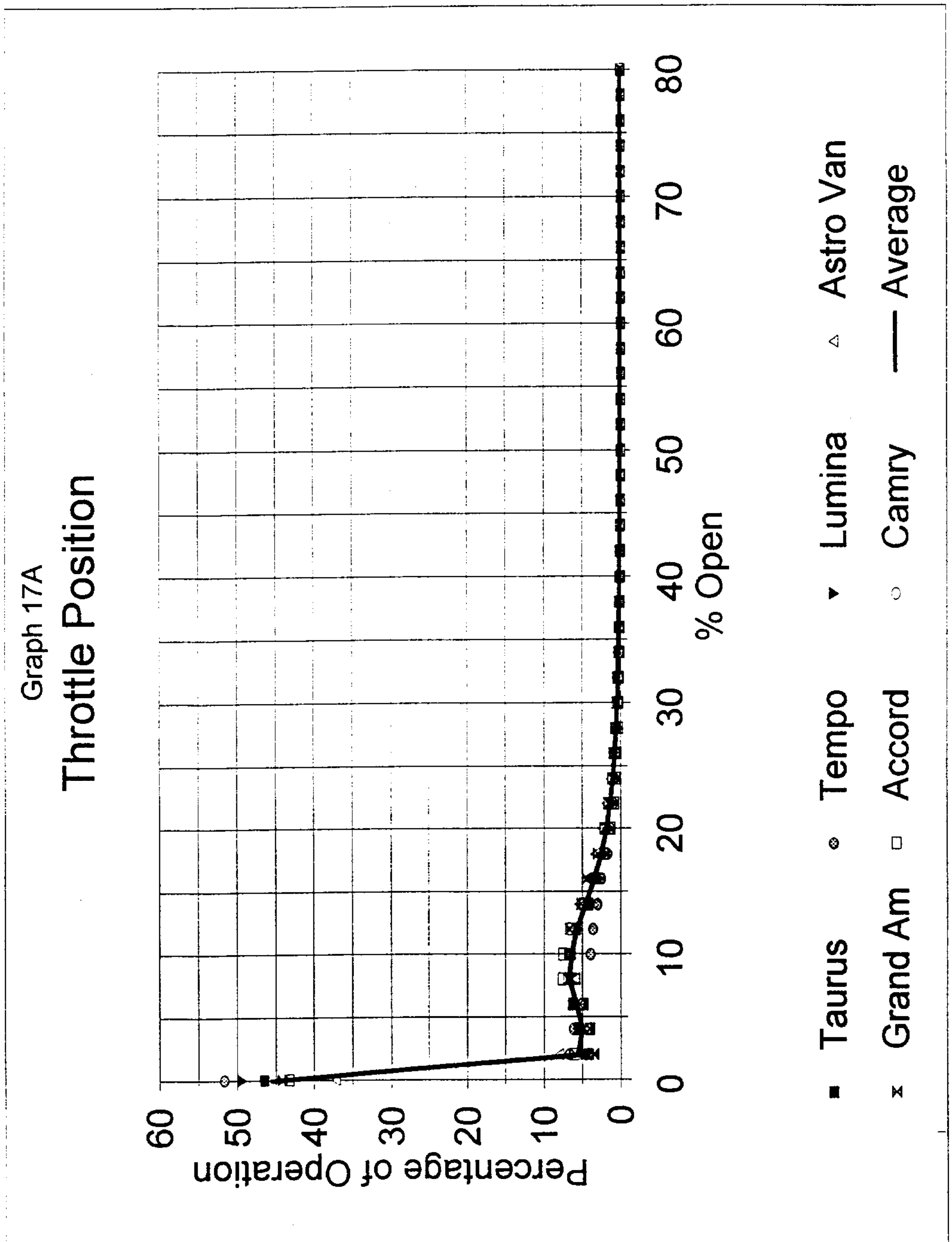
Engine Speed





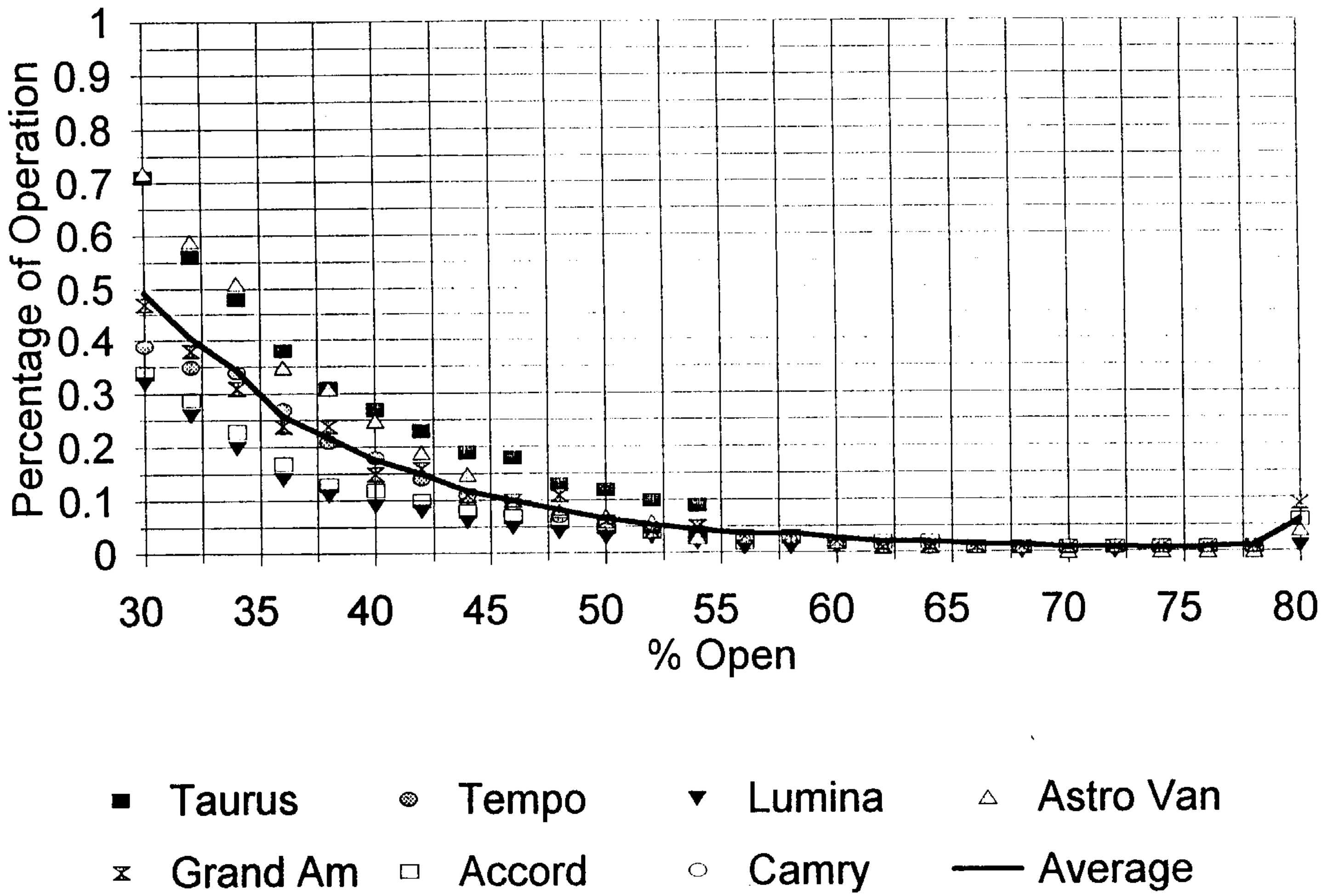
Graph 15
Air/Fuel Ratio
Percentage of Operation
40
30
20
10
0
13.4
13.6
13.8
14
14.2
14.4
14.6
14.8
15
15.2
15.4
15.6
15.8
16
Ratio
Taurus
Tempo
Lumina
Astro Van
Grand Am
Accord
Camry
Average

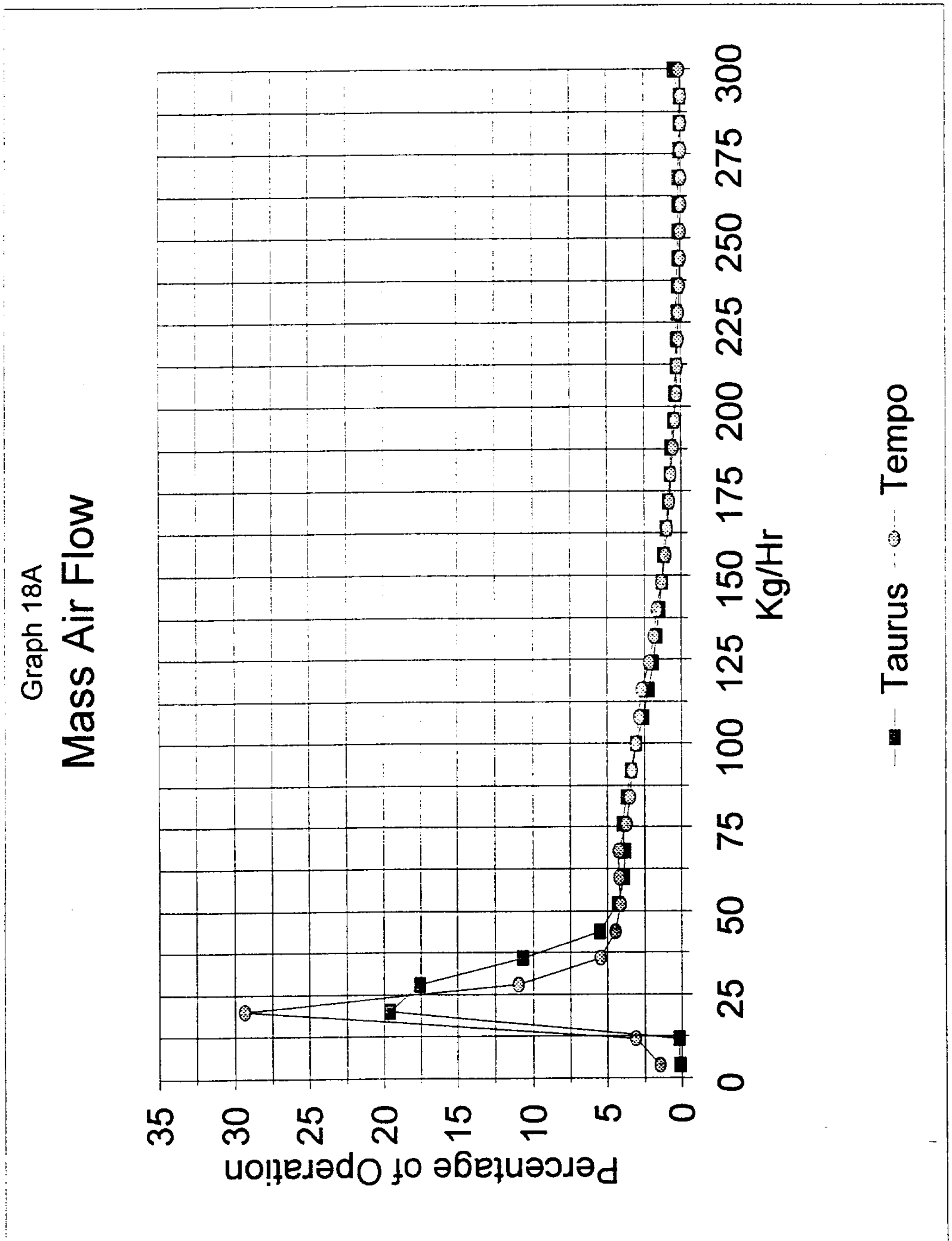

Graph 16
Oxygen Sensor Voltage
Percentage of Operation
15
10
5
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Volts
Taurus
Tempo
Lumina
Astro Van
Grand Am
Accord
Camry
Average

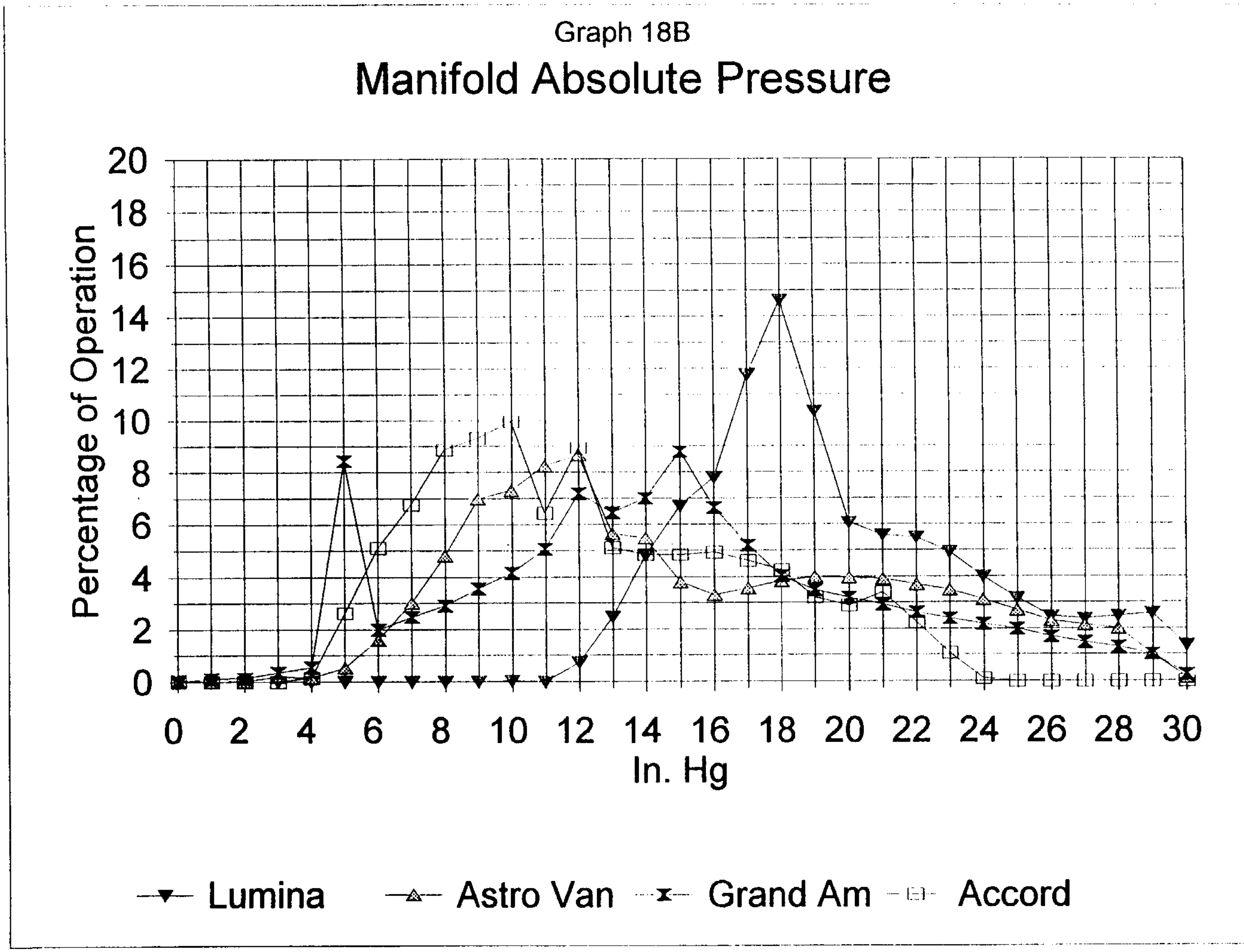

Graph 17A
Throttle Position
Percentage of Operation
60
50
40
30
20
10
0
0
10
20
30
40
50
60
70
80
% Open
Taurus
Tempo
Lumina
Astro Van
Grand Am
Accord
Camry
Average

Graph 17B

Throttle Position > 30% Open

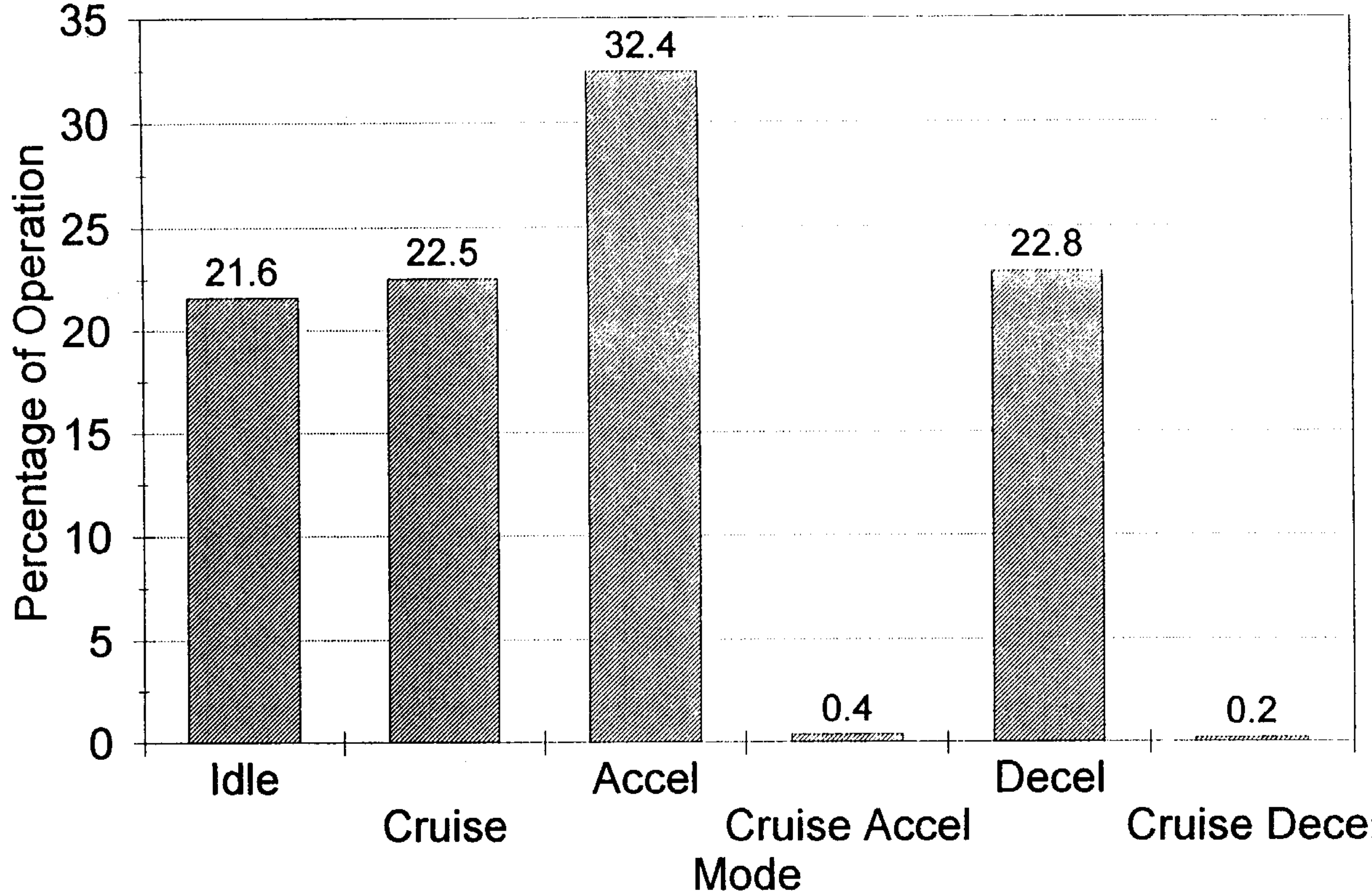



Graph 18A
Mass Air Flow
Percentage of Operation
35
30
25
20
15
10
5
0
0
25
50
75
100
125
150
175
200
225
250
275
300
Kg/Hr
Taurus
Tempo


Graph 18B
Manifold Absolute Pressure
Percentage of Operation
20
18
16
14
12
10
8
6
4
2
0
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
In. Hg
Lumina
Astro Van
Grand Am
Accord

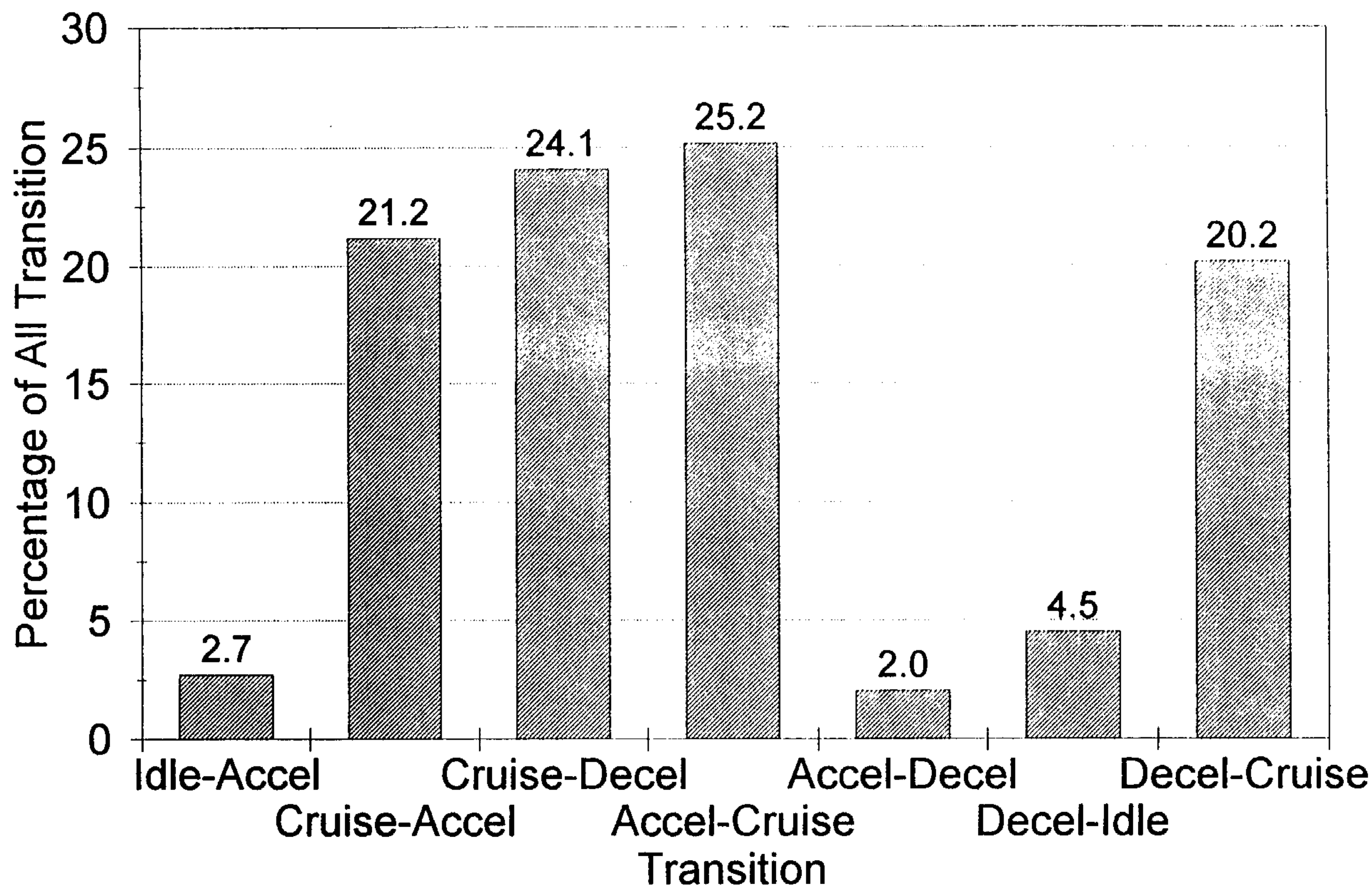
Graph 19

Modes of Operation: All Vehicles

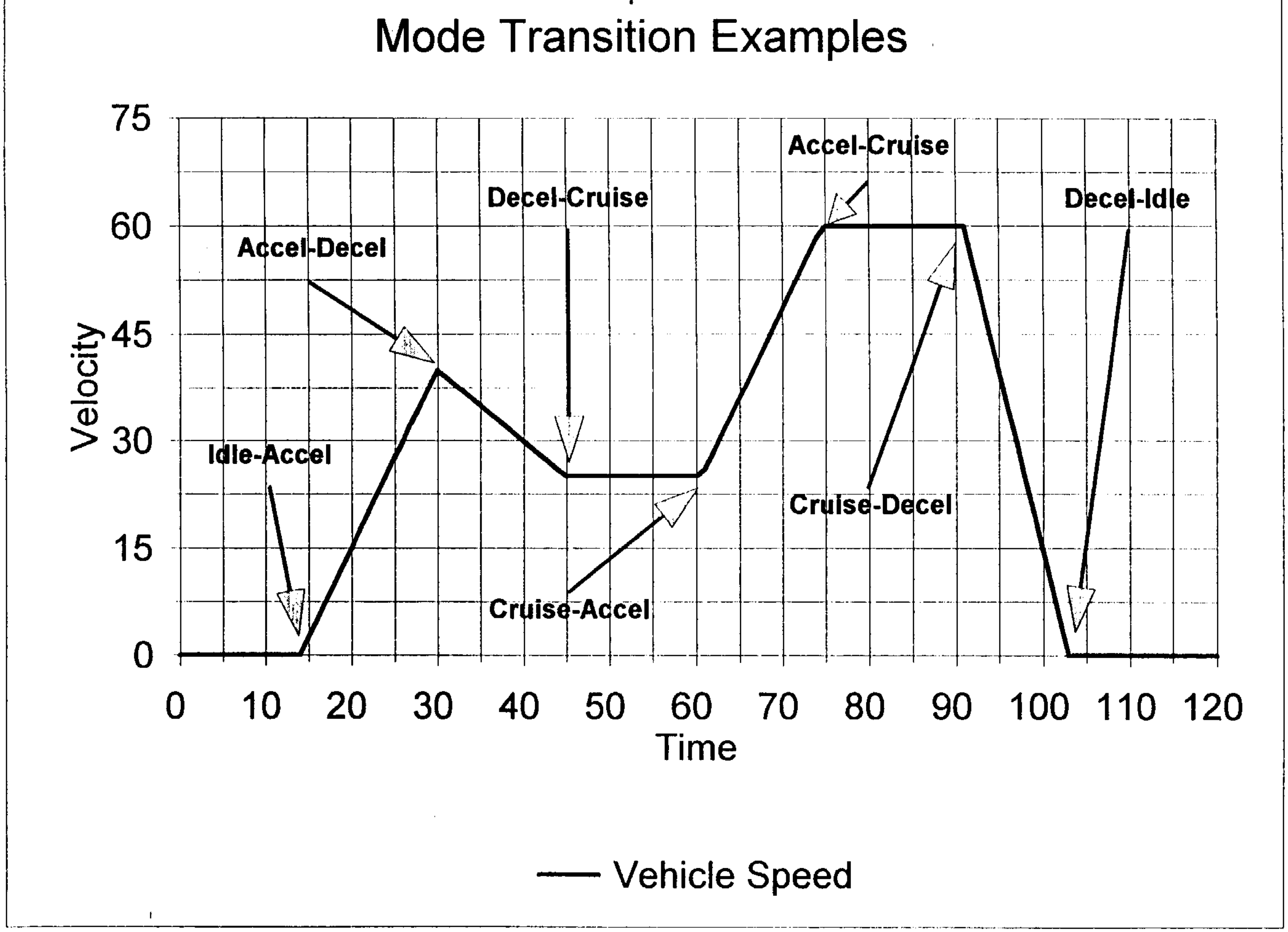


Graph 20

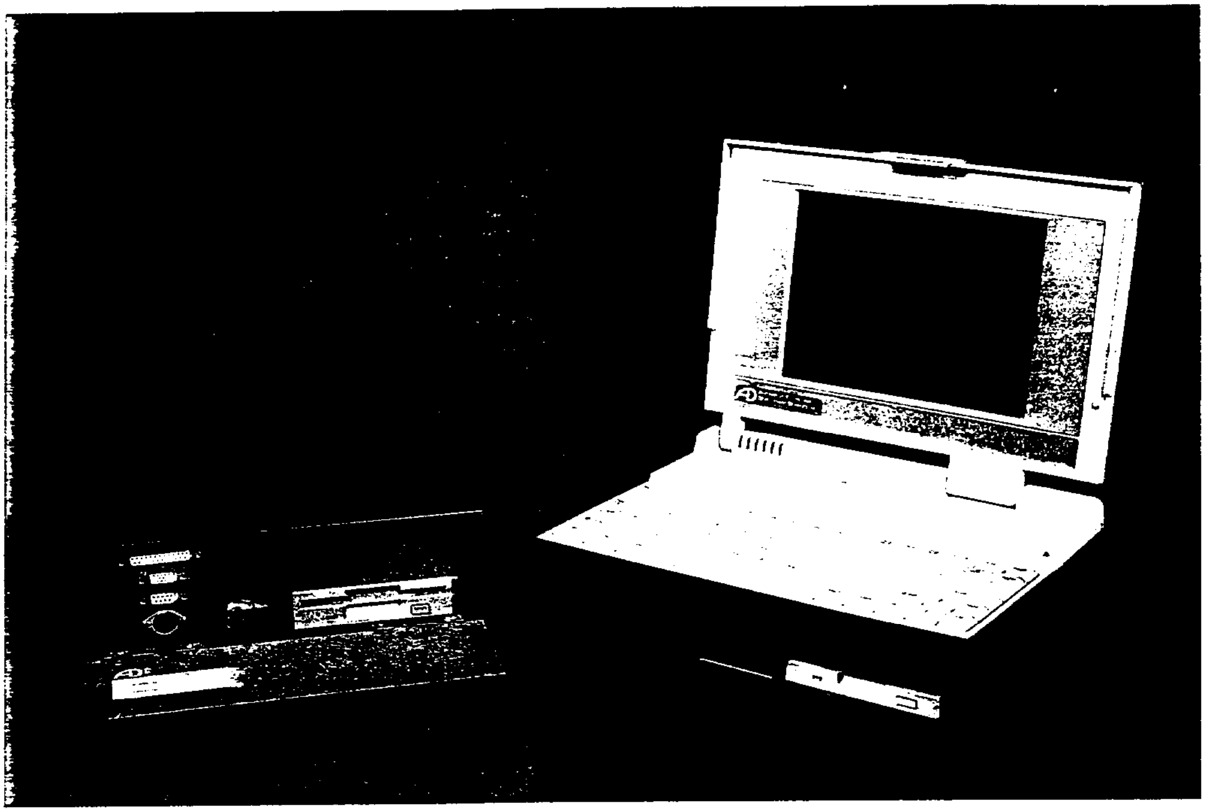
Mode Transitions: 7 Most Significant



Graph 21


Mode Transition Examples
Velocity
75
60
45
30
15
0
0
10
20
30
40
50
60
70
80
90
100
110
120
Time
Idle-Accel
Accel-Decel
Decel-Cruise
Cruise-Accel
Accel-Cruise
Cruise-Decel
Decel-Idle
Vehicle Speed

APPENDIX B: THE ATDS DATALOGGER



POWER PORTABILITY RELIABILITY

The ATDS 2000-Series Dataloggers

Automotive Testing and Development Services, Inc.

When it comes to da
ATDS delivers with tl

The ATDS 2000-Series Dataloggers are laboratory quality data acquisition instruments designed for either portable, remote, unattended operation or as part of a laboratory set-up. The ATDS Dataloggers have features which provide users a method of high-quality mobile and stationary data acquisition and storage.

The ATDS Datalogger comes in two models. The 2300 is a small, self-contained unit designed primarily for remote, unattended operation. The 2300 can become a full-function laboratory data acquisition instrument when a keyboard and monitor are attached to the appropriate 2300 ports.

The 2400 model incorporates all of the features of the 2300, plus it fully integrates an LCD color VGA display and keyboard.

Basic System Hardware

The ATDS Dataloggers are based on a custom-designed data acquisition board and a 386SL processor. The custom designed data acquisition board features 48 channels of analog and 4 channels of digital inputs, plus six additional control-level channels. The 48 analog input channels consists of 16 type-K thermocouple channels, 16 analog voltage channels, and 16 channels that can be software selected as either a frequency input channel or an analog voltage input channel.

The system is designed to store data on a high density Floptical disk system. The Floptical system will also store data on standard 3.5" floppy disk. An optional super-high density magneto-optical disk storage system is also available for increased data storage capability.

The ATDS Dataloggers have been designed to provide extensive data storage capability without the need for on board data consolidation. This feature assures that all raw data is captured and saved for future manipulation and post-processing.

System Power

The ATDS Dataloggers are designed to operate directly from a 12 volt DC source. The system has been highly integrated to reduce power consumption. Through the inclusion of an optional internal power supply, the system can be directly powered from a 110 volts AC power source of either 50 or 60 Hz. EMI/EMC protection is provided by the internal power supply.

The ATDS Dataloggers' quiescent power consumption is less than 80 milliwatts.

The 2300 peak input power requirement is 20 watts.

The 2400 peak input power requirement is 30 watts.

Sampling Rates

The ATDS Dataloggers have a base sampling rate from once every 10 miliseconds to once every 8 hours. Each input channel can have its own sampling rate, which is an integer multiple of the selected base sampling period. This allows for a 1000:1 range in sampling rates across the 48 input channels.

Size

The ATDS 2300 Datalogger is 10" wide, 3.25" high, and 8" deep. This compact size allows for a great deal of versatility in mounting and location for mobile, remote applications. The total weight is 6 pounds.

The ATDS 2400 Datalogger is 11.5" wide, 4" high and 9" deep. The total weight is 7.5 pounds. The 2400's light weight and compact size allows flexibility for both lab and field use.

Data Storage Capacity

The ATDS Dataloggers are designed to provide extensive data storage capability without the need for on board

In the lab or at a remote site, the

ta acquisition, e Dataloggers

data consolidation. This feature assures that all raw data is captured and saved for future manipulation and post-processing. All data is time tagged and check summed to ensure data integrity and to facilitate any postprocessing needs.

Data storage capacity is nominally 76 hours for 72 channels of data acquisition at a 1 Hz sampling rate.

In addition, the ATDS Dataloggers can store 72 channels of data collected at 1 Hz sampling rate, for a test up to 14 hours in length.

These operating capacities reduce the need for frequent screening or data retrieval from the system. It also eliminates the need to reduce the raw data during operation.

Installation and Hookup

The ATDS Dataloggers are easy to install and hookup. All data inputs have been conveniently located on the ergonomically designed back panel. The 16 thermocouple connectors are standard mini type-K bulkhead connectors. The analog, frequency and digital-signal inputs enter the system through two uniquely keyed 50-pin connectors. The remote "on" and the remote "data record" signals are brought in through the No. 1 analog frequency connector.

The 2300 front panel provides for manual system operation through a keyed four position switch: Auto-Off-On-Record. Also located on the front panel are system status lights, self-test switch, keyboard and monitor ports, and the Floptical disk drive. To protect, shield and secure the front panel during remote or mobile operations, a locking and sealing front panel cover is included.

Installation and operation is facilitated through audible feedback. This audible feedback allows the user to verify that the ATDS Datalogger is functional.

If speed transducers are used in the operation, the ATDS Dataloggers digital outputs can be used to control solid state relays that power the additional transducers.

Data Processing

PC based software is provided to convert the stored data into an ASCII file for use common statistical and spreadsheet PC-based programs.

Self-Test and Internal Calibration

The ATDS Dataloggers are equipped with full functional self-test and internal calibration capability at the individual input channel level. The self-test and internal calibration function can be called from the keyboard or, in the case of the 2300, through the self-test switch on the front panel.

Software Functions

The 2300, with an attached keyboard and monitor, and the 2400 have the following keyboard-controlled functions: system configuration and set-up, real time data display in either actual values, mean data values, histograms, real time strip chart actual data, real time strip chart mean data,mean data bar graphs, or actual data bar graphs. The system configuration and set-up file is saved until changed. Configuration files can be saved and recalled. The ATDS Dataloggers will always initialize in the most recently stored system configuration mode.

Environmental Limits

The ATDS Dataloggers are designed to operate over a wide range of ambient conditions. The unit can be operated over the temperature range of 0°F to 150° F. Humidity ranges from 0 to 100 percent non-condensing can be accommodated.

The ATDS Dataloggers are easy to install and hookup, with all data inputs conveniently located on the ergonomically designed back panel.

ataloggers can get the job done!

Specification Summary

STANDARD

Input Channels
16 TYPE-K THERMOCOUPLE CHANNELS
16 DEDICATED ANALOG VOLTAGE CHANNELS
16 FREQUENCY OR ANALOG CHANNELS
6 DIGITAL CHANNELS
KEYBOARD PORT — XT TYPE (2300 ONLY)
KEYBOARD (2400 ONLY)

Output Channels
2 ANALOG VOLTAGE CHANNELS
4 DIGITAL CHANNELS
MONITOR PORT — VGA TYPE (2300 ONLY)
VGA COLOR LCD (2400 ONLY)

External Data Acquisition Sync Output

External Data Acquisition Trigger Input

Data Storage Media
REMOVABLE 3.5" FLOPTICAL DISK

Data Retrieval
REMOVABLE 3.5" FLOPTICAL DISK
RS 232 SERIAL PORT DOWNLOAD
PARALLEL PORT DOWNLOAD

Data Storage Capacity — 1 Hz Sampling Rate:
16 CHANNELS — 124 HOURS
32 CHANNELS — 76 HOURS
48 CHANNELS — 54 HOURS

Single Event Trap — 1 Hz Sampling Rate:
16 CHANNELS — 22 HOURS
32 CHANNELS — 14 HOURS
48 CHANNELS — 10 HOURS

Sampling Rate
INDIVIDUAL CHANNEL RATE SELECTABLE.
MAXIMUM RATE IS 100 Hz

Weight:
2300 — 6 POUNDS
2400 — 7.5 POUNDS

Dimensions
2300 — 10" x 3.25" x 8"
2400 — 11.5" x 4" x 9"

Power Consumption
ACTIVE — 20 WATTS MAX (2300)
ACTIVE — 30 WATTS MAX (2400)
QUIESCENT — LESS THAN 80 MILLIWATTS

Voltage Requirements
10 TO 16 VDC

Initialization Time
10 SECONDS

Operating Temperature Range
0° F TO 150° F

OPTIONS

High Data Storage Capacity
(Data Capacity — 1 Hz Sampling Rate:)
16 CHANNELS — 744 HOURS
32 CHANNELS — 456 HOURS
48 CHANNELS — 324 HOURS

Expanded Single Event Trap — 1 Hz Sampling Rate
16 CHANNELS — 58 HOURS
32 CHANNELS — 34 HOURS
48 CHANNELS — 24 HOURS

AC Power Operation
VOLTAGE REQUIREMENTS — 110 VAC 50/60 Hz

CORPORATE OFFICES

400 S. Etiwanda Ave. ■ Ontario, CA 91761
Tel: 909.467.3629 Fax: 909.988.0319

APPENDIX C: DATALOGGER DOWNLOADING PROCEDURE

Downloading Data from the ATDS Datalogger (hard drive equipped version)

- ❑ Open unit case.
- ❑ Insert video and tape drive controller cards.
- ❑ Connect power to tape drive and datalogger unit.
- ❑ Connect keyboard and monitor.
- ❑ Insert XT Gold diskette into disk drive.
- ❑ Power up datalogger.
- ❑ Copy all files from XT Gold diskette to c:\counts directory. If directory does not exist, create one.
- ❑ Replace XT Gold diskette with Conversion diskette.
- ❑ Run the execute.bat file to convert data from binary to raw ascii format.
- ❑ Reboot datalogger with XT Gold diskette.
- ❑ Verify that converted files exit.
- ❑ Run the tape.exe file to back up all files to the tape drive.
- ❑ Delete all files except the datalog.tmp file.
- ❑ Insert blank formatted diskette into disk drive.
- ❑ Remove video and tape controller cards.
- ❑ Close unit case.

APPENDIX D: PROGRAM PARTICIPANTS

Ford Taurus Participants

# City	Zip	Co.	Start	Vehicle
1 Riverside	92503	RV	3/31/93	1986 Nissan 200SX
2 Bellflower	90706	LA	6/7/93	1992 Toyota Camry
3 Riverside	92509	RV	6/16/93	1984 Chevrolet El Camino
4 Newport Beach	92660	OR	7/21/93	1983 Toyota Tercel
6 Pomona	91768	LA	08/30/93	1989 Nissan Sentra
7 Long Beach	90813	LA	09/09/93	1989 Saab 9000CD Turbo
8 Canyon Country	91351	LA	09/20/93	1989 Mercury Tracer
9 Diamond Bar	91765	LA	10/07/93	1985 Honda Accord LX
11 Northridge	91325	LA	11/12/93	1985 Lincoln TownCar
12 Southgate	90280	LA	01/12/94	1988 Honda Accord
13 Costa Mesa	92626	OR	02/02/94	1985 Honda Accord
14 Mira Loma	91752	RV	02/14/94	1987 Ford Van
15 Redondo Beach	90277	OR	03/04/94	1987 Ford

Chevrolet Astro Van Participants

# City	Zip	Co.	Start	Vehicle
1 Montrose	91020	LA	03/24/93	1985 Toyota Corolla GTS
2 Granada Hills	91544	LA	04/09/93	1988 Ford Taurus
3 Canoga Park	91304	LA	05/27/93	1991 Isuzu Rodeo
4 Pasadena	91107	LA	06/15/93	1984 Toyota Tercel
5 Yorba Linda	92686	OR	06/28/93	1983 Chevrolet S-10
6 Corona	91720	RV	08/19/93	1989 Honda Accord
7 Valley Village	91607	LA	09/21/93	1989 Nissan Maxima
10 Granada Hills	91344	LA	11/19/93	1988 Ford Taurus
11 Redlands	92373	SB	12/08/93	1989 Dodge Caravan
12 Claremont	91711	LA	01/03/94	1985 Ford Tempo
13 Downey	90242	LA	01/11/94	1988 Jeep Cherokee
14 Los Alamitos	90720	OR	01/27/94	1987 Dodge Caravan
15 Santa Ana	92705	OR	02/11/94	1988 Mitsubishi Van
16 Stanton	91680	OR	03/07/94	1987 Dodge Diplomat
17 La Habra	90631	OR	05/18/94	1990 Plymouth Grand Voyager

Toyota Camry Participants

# City	Zip	Co.	Start	Vehicle
2 Rialto	92376	SB	06/22/93	1992 Toyota Pick-up
3 Gardena	90247	LA	07/08/93	1990 Ford Country Squire
4 Garden Grove	92644	OR	08/12/93	1984 Toyota Camry
5 Santa Ana	92707	OR	08/24/93	1984 Toyota SR5 Pick-up
6 Mission Viejo	92692	OR	09/09/93	1989 Hyundai Sonata
7 Paramount	90723	LA	10/01/93	1983 Oldsmobile Omega
8 Long Beach	90802	LA	12/28/93	1985 Nissan Sentra
10 Newhall	91321	LA	01/10/94	1988 Lincoln Continental
11 Valencia	91355	LA	02/15/94	1987 Honda Accord
12 Downey	90242	LA	05/18/94	1990 Chrysler Lebaron
13 Duarte	91010	LA	06/09/94	1985 Volkswagen GTI

Ford Tempo Participants

# City	Zip	Co.	Start	Vehicle
1 Ontario	91761	SB	03/30/93	1990 Plymouth Colt
2 Sepulveda	91343	LA	04/12/93	1991 Honda Civic
3 Compton	90222	LA	04/27/93	1983 Ford Escort
4 Mission Viejo	92692	OR	05/05/93	1985 Toyota Corolla GTS
5 Los Angeles	90034	LA	06/15/93	1990 Ford Probe
6 Malibu	90265	LA	06/28/93	1984 Honda Accord
7 Montebello	90640	LA	08/12/93	1987 Honda Accord
8 Inglewood	90302	LA	08/23/93	1984 Isuzu Impulse
9 Perris	92370	RV	09/01/93	1985 Ford Ranger
10 Temple City	91780	LA	09/22/93	1989 Ford Ranger
11 Buena Park	90621	OR	10/05/93	1988 Ford Taurus
12 Glendora	91740	LA	03/29/94	1987 Nissan Pick-up
13 Valinda	91744	LA	04/12/94	1988 Ford Ranger

Pontiac Grand Am Participants

# City	Zip	Co.	Start	Vehicle
1 Yucaipa	92399	SB	04/06/93	1986 Nissan Pulsar
3 Newport Beach	92663	OR	06/24/93	1989 Ford Escort
4 Long Beach	90815	LA	08/04/93	1985 Toyota Supra
6 Santa Ana	92705	OR	09/16/93	1990 Chevrolet Lumina
7 Long Beach	90814	LA	10/01/93	1986 Suzuki Samurai
8 Alta Loma	91701	SB	11/01/93	1983 Club Wagon
9 Santa Clarita	91351	LA	01/20/94	1985 Nissan 300ZX
10 Cypress	90630	OR	04/02/94	1987 Toyota Tercel
11 Long Beach	90808	LA	09/14/94	1985 Mercury Marquis
12 Whitter	90604	LA	12/21/94	1987 Chrysler 5th Ave
13 North Hollywood	91605	LA	01/10/95	1986 Ford Bronco
14 Temecula	92592	RV	01/27/95	1987 Pontiac Grand Am
15 Los Angeles	90026	LA	02/08/95	1987 Dodge Ram 50

Chevrolet Lumina Participants

# City	Zip	Co.	Start	Vehicle
1 Rancho Santa Ma	92688	OR	04/08/93	1987 Olsmobile Achieva
2 San Bernardino	92404	SB	06/10/93	1990 Chevrolet 1/2 ton Pick-up
3 Mission Viejo	92691	OR	06/23/93	1984 Nissan Pulsar
4 Walnut	91789	LA	08/17/93	1984 Toyota Supra
6 Idyllwild	92349	RV	09/14/93	1983 Nissan 4X4
7 Los Angeles	90019	LA	09/22/93	1990 Chevrolet Cavalier
8 Long Beach	90814	LA	10/12/93	1985 Subaru Coupe GL
9 Los Angeles	90045	LA	10/22/93	1985 Buick Century
10 Cucamonga	91730	SB	02/25/94	1985 Subaru Wagon
11 Van Nuys	91406	LA	03/04/94	1988 Chevrolet Camaro IROC-Z
12 Huntington Beac	92647	OR	03/18/94	1988 Toyota Camry
13 West Hills	91304	LA	03/31/94	1987 Mercury Sable
14 Norwalk	90650	LA	04/14/94	1987 Mazda

Honda Accord Participants

# City	Zip	Co.	Start	Vehicle
1 Redondo Beach	90277	LA	05/21/93	1991 Acura Integra
2 Grand Terrace	92324	LA	06/09/93	1986 Nissan King Cab
4 Tustin	92680	OR	08/11/93	1990 Mazda MX-6 Turbo
6 Los Angeles	90066	LA	12/14/93	1994 Honda Civic Wagon
7 Laguna Niguel	92806	OR	03/02/94	1983 Mitsubishi Tredia
8 Canoga Park	91306	LA	04/20/94	1990 Honda Civic LX
9 Los Angeles	90037	LA	05/24/94	1989 Chrysler Lebaron
10 Fullerton	92632	OR	06/28/94	1984 Volvo Sedan
11 West Covina	91792	LA	07/25/94	1989 Oldsmobile Ciera
12 Los Alamitos	90720	OR	08/24/94	1985 Mercury Grand Marquis
13 Canyon Country	91351	LA	09/06/94	1988 Toyota Camry
14 Cerritos	90701	LA	10/14/94	1989 Honda Civic
15 Santa Ana	92703	OR	11/04/94	1987 Ford
16 Tustin	92680	OR	12/30/94	1991 Toyota Tercel
17 Costa Mesa	92626	OR	01/10/95	1990 Honda Civic
18 Colton	92324	SB	01/20/95	1989 Dodge Colt
19 Rancho Santa M	92688	OR	02/09/95	1988 Toyota Pick-up
21 Reseda	91335	LA	02/17/95	1986 Nissan 4x4

County	Number	%
Los Angeles	54	56.3%
Orange	27	28.1%
San Bernardino	8	8.3%
Riverside	7	7.3%
Total	96	100.0%