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Aerodynamic Characteristics of Sixteen Electric, Hybrid, and Subcompact Vehicles

Complete Data

Donald W. Kurtz

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PREFACE

The Electric and Hybrid Vehicle (EHV) Research, Development, and Demonstration Act of 1976, Public Law 94-413, later amended by Public Law 95-238, established the governmental EHV policy and the current Department of Energy EHV Program. The EHV System Research and Development Project, one element of this Program, is being conducted by the Jet Propulsion Laboratory (JPL) of the California Institute of Technology through an agreement with the National Aeronautics and Space Administration. This report presents an EHV aerodynamic data base, a component of the FY '78 investigations conducted under the Aerodynamic Resistance Reduction work element. This work element is a part of the Supporting Vehicle Technology Task and Vehicle Systems Development Task Area.

ACKNOWLEDGEMENT

The author wishes to acknowledge the long hours, attention to detail, and willingness to respond to unusual test requirements demonstrated by Ed Payne, Lockheed wind tunnel operations supervisor, and Dan Bruce, Lockheed wind tunnel project engineer. Special thanks are due to Harold Holway, Member Technical Staff, JPL, who managed many of the vehicle loan and shipping arrangements and coordinated the vehicle setup procedures in the wind tunnel.

SUMMARY

This report presents an elementary electric and hybrid vehicle aerodynamic data base and describes how it was developed. Sixteen electric, hybrid, and subcompact production vehicles were tested in the Lockheed-Georgia low-speed wind tunnel. Zero-yaw drag coefficients ranged from a high of 0.58 for a boxey delivery van and an open roadster to a low of about 0.34 for a current four-passenger prototype automobile which was designed with aerodynamics as an integrated parameter. Vehicles were tested at yaw angles up to 40 degrees and a wind weighting analysis is presented which yields a vehicle's effective drag coefficient as a function of wind velocity and driving cycle. Other parameters investigated included the effects of windows open and closed, radiators open and sealed, and pop-up headlights.

Complete six-component force and moment data are presented in both tabular and graphical formats. Only limited commentary is offered since, by its very nature, a data base should consist of unrefined reference material.

A justification for pursuing efficient aerodynamic design of EHVs is presented which demonstrates the partitioning of the road energy requirement and the dependence of range upon the aerodynamic drag component over an electric vehicle driving cycle.

Establishing this data base is one required element of a larger task, the purpose of which is to develop an aerodynamic design guide for use by the EHV industry.

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SECTION I

INTRODUCTION

As an automobile moves along a road surface, the resulting displacement of air gives rise to various forces and moments which are proportional to the square of the velocity. The power required to overcome aerodynamic drag, which is proportional to the cube of the velocity, has long been recognized as a significant road-load at high cruise speeds. Estimates of significant fuel savings have therefore led to a reduction of the maximum speed limit from 65 to 55 mph on U. S. highways. There is, however, a common belief that, as speeds decrease to those characteristic of urban vehicles in general and electric vehicles in particular, the effect of aerodynamics quickly fades. Investigations with vehicle simulators show that over the EPA Urban Driving Cycle, only 20% of the total road-energy is required to overcome aerodynamic resistance for a typical subcompact vehicle. Most electric vehicles, however, do not have the performance capabilities required to follow the EPA cycle; therefore, the Society of Automotive Engineers (SAE) has developed a series of cycles specifically for electric vehicle evaluations (Recommended Practice Test Procedure SAE J227a). Over an SAE J227a D Cycle (maximum speed, 72 kph), more than 35% of the energy at the road-wheel interface goes to overcome aerodynamic drag for a typical subcompact electric vehicle with no regenerative braking (weight = 1350 kg, rolling resistance = 1.2% of the vehicle weight, and the drag coefficient-frontal area product = 0.9 m^2) (see Figure 1). The addition of regenerative braking could increase the relative aerodynamic contribution to almost 40% in this case (since the inertial component would be reduced).

It is reasonable to expect that, with vigorous design efforts, a drag area (CDA)* of 0.54 m^2 (5.8 ft^2) may be achievable - a 40% reduction from the 0.9 m^2 (9.7 ft^2) drag area which is typical of today's subcompact car. Figure 2, generated with the aid of JPL's electric vehicle computer simulator (ELVEC), shows that this could result in an 18% increase in the SAE J227a D cycle range. To achieve a similar benefit via a reduction in rolling resistance would require a 50% reduction (from 1.2%) to about 0.6% (a rather unrealistic level since this includes all rolling losses in addition to that due to the tires) or a 22% reduction in vehicle weight (300 kg). These examples, although simplified, tend to demonstrate the potential benefits from, and justification for efforts to reduce the aerodynamic resistance of EHVs.

It should also be pointed out that electric vehicles (EVs) have certain inherent attributes which are aerodynamically beneficial. The internal aerodynamic losses, associated with radiator airflow for an internal combustion (IC) engine counterpart, are not a factor for electric vehicles (EVs). Also, full belly pans, which have given rise to

*The drag coefficient, CD, is nondimensional; A is the vehicle's projected cross sectional area. Both are defined along with the other force and moment coefficients in Appendix A.

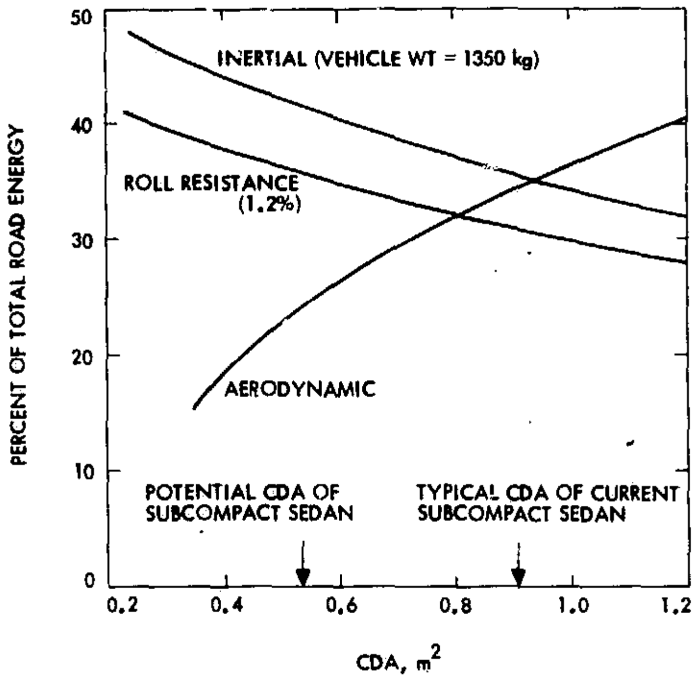

Figure 1. Road Energy Component Split Over the SAE J227a D Driving Cycle (No Regenerative Braking)

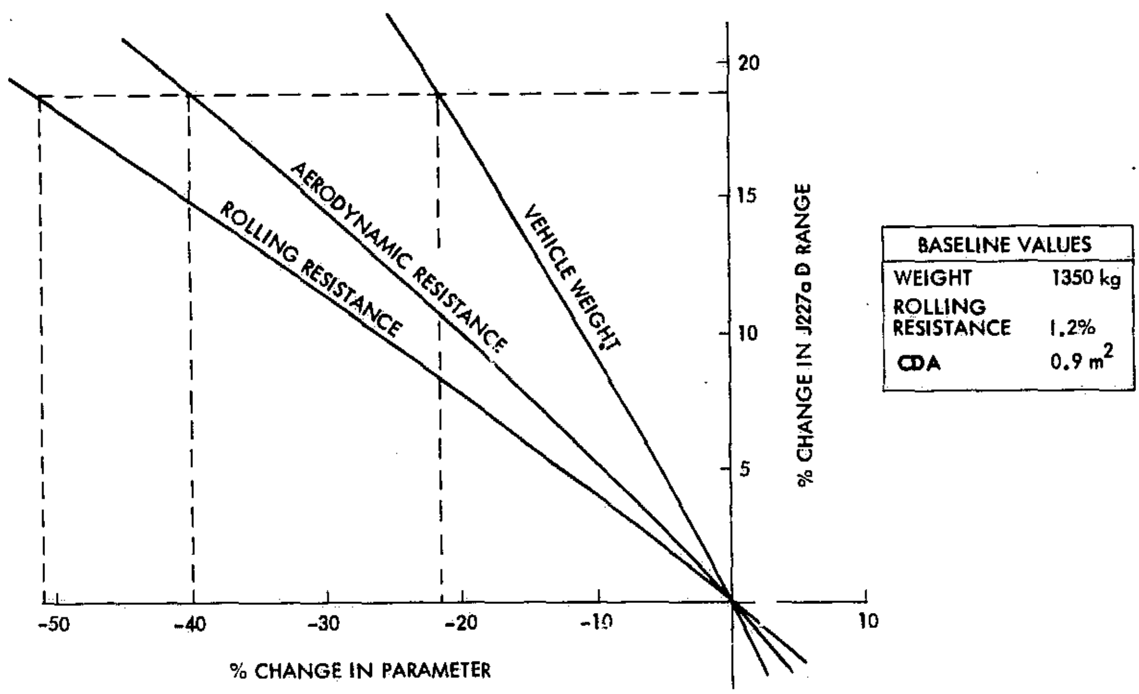

Figure 2. Projected Vehicle Range Over the SAE J227a D Cycle as a Function of Various Parameters (No Regenerative Braking)

safety and maintenance objections in IC engine cars, may be quite acceptable in an EV. These two considerations alone could reduce the drag of an EV by as much as 20% over an IC engine equivalent. It should be noted that the requirements for battery volume and placement may dictate ranges of body proportions which are quite different from those of conventional automobiles. Center longitudinal battery tunnels, for instance, can cause a vehicle to be unusually wide; smaller motors and potentially more compact drive lines may allow a significant redistribution of proportions. These differences, however, could have either beneficial or detrimental aerodynamic consequences.

SECTION II

OBJECTIVES AND APPROACH

The overall objective of this work element is to provide the necessary trade-off information to industry to aid in the development of aerodynamically-efficient electric and hybrid vehicles, and specifically, to develop simplified aerodynamic design principles and procedures suitable for use by the (EHV) industry. The approach being used is to develop an aerodynamic design logic path which will provide a strategy and guide through progressively more refined levels of design. The process of developing this logic path exposes many technological gaps and information voids manifest in various path elements. The information supplied by a reliable aerodynamic data base is crucial to this process and is specifically required in order to:

(1) Extend, develop, and refine drag prediction techniques.

(2) Develop generalized relationships between drag and yaw angles.

(3) Quantify the uncertainty in drag prediction techniques and subscale wind tunnel test results as applied to estimating actual vehicle drag on the road.

(4) Develop and quantify general aerodynamic design principles.

Very little reliable aerodynamic data on conventional automobiles is available, and virtually none on special electric or hybrid vehicles. The automobile manufacturers, both foreign and domestic, have generated a great deal of aerodynamic information for IC engine vehicles, but it remains largely proprietary. Most of the data that is available is from subscale wind tunnel tests of questionable or unknown origin. Here lies a basic problem with random wind tunnel data: it is usually not directly comparable. Owing to such factors as scale, level of detail (internal flow paths, undercarriage, etc.), flow conditions, and data reduction procedures, the absolute values of the coefficients are of limited value. The difference in measured drag between a "reasonably detailed" scale model and the full-sized production vehicle is often 20% or greater. The same automobile tested in two different wind tunnels may yield drag results which differ by 10%. The magnitude of various wall corrections alone can modify the drag by 10%. To maximize its usefulness, a data base should be generated at the same model scale, in the same tunnel, under the same conditions, and be handled using identical data reduction procedures. The relative effects represented by the data base should then be sufficiently reliable. Correlations with road test results can help to establish a confidence level for the absolute values.

With this background in mind, it was determined that the development of an EHV aerodynamic data base was required and should be initiated by performing full-scale tests in the Lockheed-Georgia low-speed wind

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tunnel. This report presents the results of that investigation and constitutes an elementary EHV aerodynamic data base. The information contained herein will later be used to help evaluate drag estimation procedures, and to develop confidence levels on predictions from analysis and subscale wind tunnel test results. These tests were performed during the period from July 5 through July 8, 1976 and are officially designated as LSWT Test 291.

SECTION III

TEST DESCRIPTION

A. TEST VEHICLES

In order to begin assembling a meaningful data base, a representative range of vehicle types was desired. A Request for Quotation (RFQ) was prepared and sent to 25 possible owners or developers of electric or hybrid vehicles asking for the use of a vehicle for aerodynamic characterization testing during a specific time period. Nine bids were received before the RFQ closing date. The selection criteria used were:

(1) Availability.

(2) Compatibility with wind tunnel balance system.

(3) Aerodynamic interest.

(4) Loan and transportation fees.

Four vehicles were selected by this process. In addition, three electric vehicles were loaned by NASA's Lewis Research Center. To supplement the group, several conventional IC subcompacts were borrowed from local dealerships and individuals. In three cases, a facsimile of an IC engine/EHV conversion was substituted. The vehicles tested in this group are shown in Figure 3 and are listed in Table 1.

B. TEST FACILITY

A detailed description of the Lockheed-Georgia low-speed wind tunnel and its associated systems is presented in Reference 1. The wind tunnel is a closed test section, single return type with two test sections in tandem as shown in Figure 4. The low speed test section where these tests were conducted is 4.95 m (16 ft) high, 7.08 m (23 ft) wide, and 13.1 m (43 ft) long.

The main external balance is a null type system which measures the six component forces and moments using precision weighbeams. Each weighbeam is balanced by moving a jockey weight along the length of the beam. The position of the jockey weight on the weighbeam is a function of the applied load. The jockey weight position is determined by an optical encoder whose output is converted to the appropriate signal for entry into the data acquisition system.

The wind tunnel main drive system consists of the motor, fan, and counterrotation vanes. The electrically powered, air cooled, 6.7 megawatt (9000 horsepower) main drive motor is coupled directly to the 12 m (39 ft) diameter, fixed-pitch, six-bladed fan. Five fixed counterrotation vanes are installed downstream of the fan to remove the rotational velocity component produced by the fan. The motor speed can be varied from 15 to 330 RPM yielding a continuous range of test section velocities from 12 m/s (28 mph) to 112 m/s (250 mph).

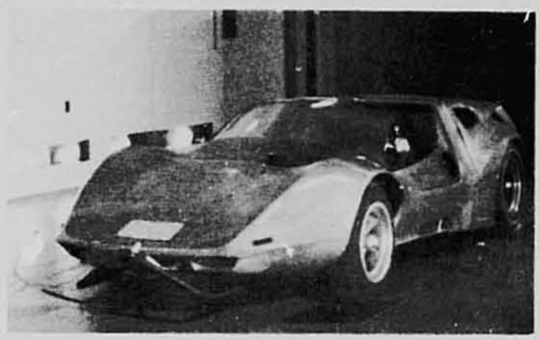
a. Otis Van

b. Chevrolet Chevette

c. Plymouth Horizon

d. AMC Pacer Wagon

e. AMC Pacer Sedan



f. Kaylor GT

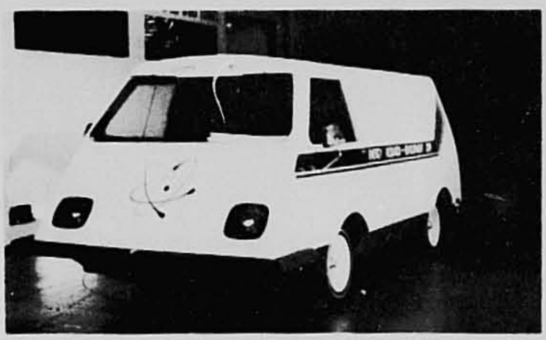
g. GE Centennial Electric

h. Oldsmobile Delta 88 Sedan

Figure 3. Test Vehicles

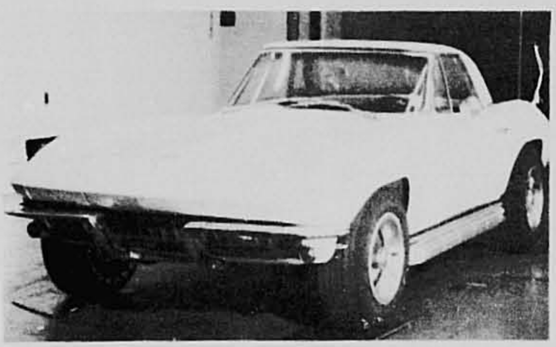
i. Honda Civic Sedan

j. Honda Civic Wagon



k. Energy R&D HEVAN

l. Ford Fiesta



m. Chevrolet Corvette

n. CDA Town Car

o Sebring-Vanguard Citicar

p. Zagato Elcar

Figure 3. Test Vehicles (Contd)

Table 1. Data Base Vehicles

Figure	Vehicle	Type
3a	Otis Elevator Co.: Otis P-500A Van[1]	Electric delivery van
3b	General Motors Corp.: 1978 Chevrolet Chevette 4-door	Internal combustion engine
3c	Chrysler Corp.: 1978 Plymouth Horizon 4-door	Internal combustion engine
3d	American Motors Corp.: 1978 Pacer Station Wagon	Internal combustion engine[2]
3e	American Motors Corp.: 1978 Pacer Sedan	Internal combustion engine
3f	Kaylor Energy Products: Kaylor GT	2-passenger hybrid-electric open roadster
3g	General Electric Co.: Centennial Electric[3]	4-passenger electric commuter
3h	General Motors Corp.: 1978 Oldsmobile Delta 88 2-door	Internal combustion engine[4]
3i	Honda Motors: 1978 Civic Sedan	Internal combustion engine
3j	Honda Motors: 1978 Civic Wagon	Internal combustion engine
3k	Energy Research and Development Corp.: HEVAN (Hybrid Electric Van)	Hybrid-electric delivery van
3l	Ford Motor Co.: 1978 Fiesta	Internal combustion engine
3m	General Motors Corp.: 1967 Chevrolet Corvette	Internal combustion engine[5]
3n	Copper Development Association: Town Car	2-passenger electric commuter
3o	Sebring-Vanguard: Citicar[1]	2-passenger electric commuter
3p	Zagato-Elcar Corp.: Elcar[1]	2-passenger electric commuter

Table 1. Data Base Vehicles (Contd)

Figure	Vehicle	Type

Table Notes

[1] Loaned by NASA-Lewis Research Center, Cleveland, OH.

[2] This production IC engine Pacer Wagon represented a reasonable facsimile of the Electric Vehicle Associates "Change of Pace" converted electric Pacer Wagon.

[3] When these tests were performed, the Centennial was identified only as the GE "Reference Electric Vehicle"; that designation therefore appears on the data sets in Appendix B.

[4] This production IC engine Delta 88 was a reasonable facsimile of the National Motors Hybrid-Electric Gemini II. Here the radiator was not blocked since the hybrid vehicle retains its V-6 engine and cooling system.

[5] This production IC engine Corvette represented a reasonable facsimile of the Cutler-Hammer Electric '67 Corvette of Santini. The front grille was blocked in order to eliminate the radiator losses, which are not present in the electric version.

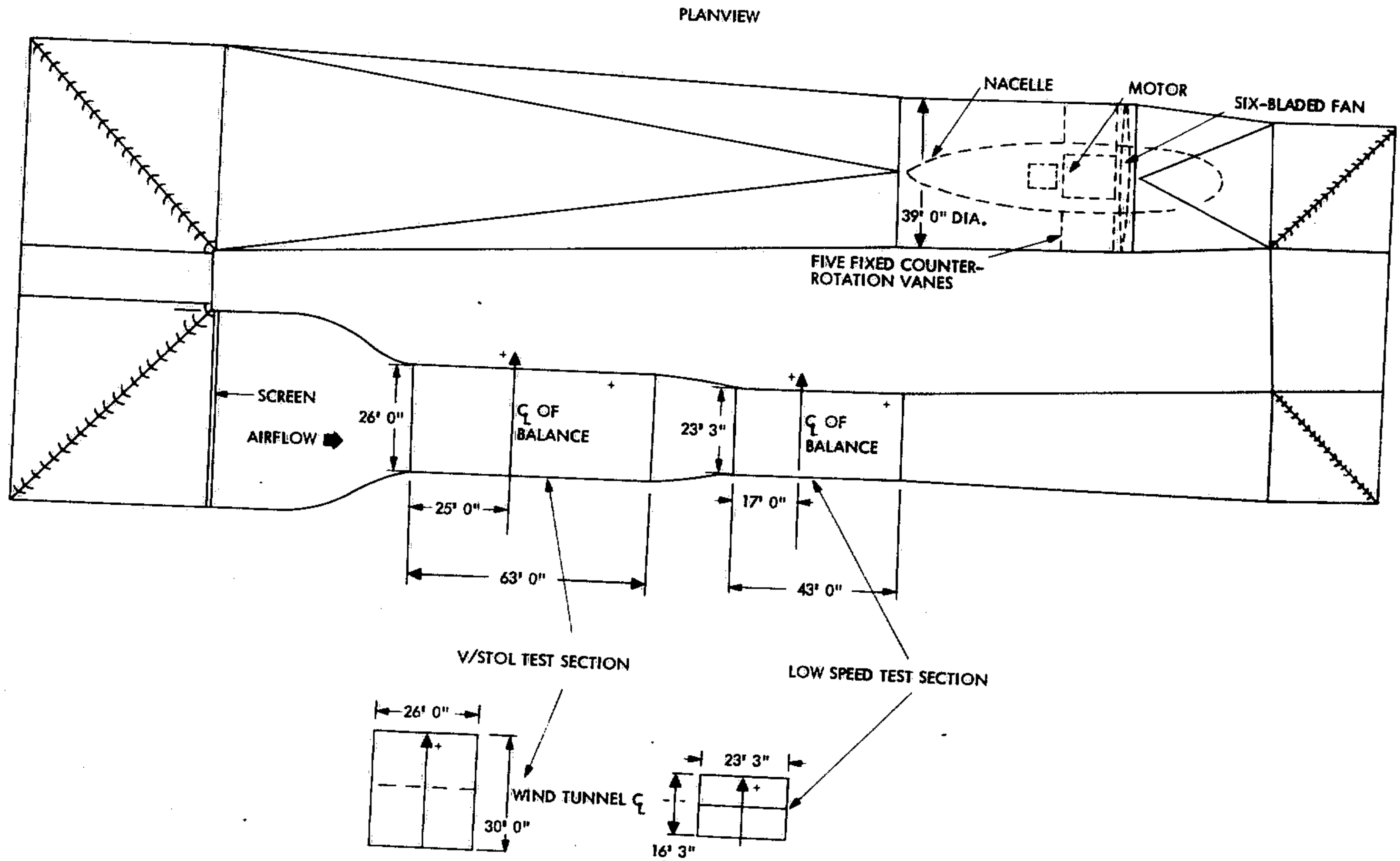


Figure 4. General Arrangement - Lockheed-Georgia Low-Speed Wind Tunnel

The center of the data acquisition system is a Control Data Corporation 1700 computer and its peripherals. Raw data are sampled over a selected period, averaged, and recorded and stored on magnetic tape for subsequent off-line reduction. These data are printed on-line in raw form by a 450 line per minute printer. Reduced freestream conditions, main balance data, and pressure data are written in FORTRAN. Programs for specific model data reduction requirements are also written in FORTRAN and are executed on-line in conjunction with the standard programs. All on-line data are backed up by off-line execution of the programs which reduce the raw data that are stored on magnetic tape. This off-line reduction provides data in more compact formats than that presented on-line.

C. TEST CONDITIONS

The vehicles were installed in the test section on a four-point support system which was attached to the six-component external main balance located below the test section floor. A circular section in the tunnel floor containing the support pads was free to rotate providing yaw angles up to 180 degrees. The vehicles were not attached to the support system, but the wheels and friction between the tires and support pads was sufficient to maintain model position. The Kaylor, Town Car, Citicar, and Elcar did not have operable brake systems. It was therefore necessary to install chocks forward and aft of the wheels to keep them in position. The vehicles were aligned in yaw and their location right or left of the balance center was determined by suspending a plumb bob from both ends and measuring the displacement from the balance longitudinal centerline. In similar manner, fore and aft location was determined by suspending a plumb bob from points midway between the axles on each side of the vehicles.

The wheel mounting pads are designed to accommodate a range of automobile wheelbases and widths and are larger than the automobile tire footprints. The exposed pad area around each tire causes a balance tare load equivalent to the exposed area multiplied by the differential pressure between the test section floor and the low-speed balance room. The wheel mounting pads are instrumented with an array of pressure orifices which were connected to manifolds so that the average pressure from each pad could be measured. The individual pad pressure tare loads were then computed for correcting lift, pitching moment, and rolling moment data. The wheel mounting pads were equipped with extension plates to accommodate the shorter wheel bases of the Elcar, Citicar, and Town Car. These raised the position of the vehicle in the tunnel by approximately 3 centimeters (Figure 5). To quantify the effect of this position change, tests were made using spacers with a few of the vehicles that were capable of using the unmodified pads. Since the suspension systems of all of the cars tested remained in the normal road condition, the body was free to move on the chassis in response to the aerodynamic forces imposed in the wind tunnel (the single exception was the GE

Figure 5. Cantilevered Pad Installation Which Elevated Vehicle Approximately 3 cm (Left Rear Wheel of CDA Town Car Shown)

Centennial whose unfinished suspension system was rigidly held in place). In order to simulate attitude changes due to passengers, 135 kg (300 lb) weights were added to the front seat area of all vehicles.

The IC engine vehicles, with one exception (see Table 1), were tested with their grilles covered. This was believed to be more representative of electric vehicles, which would not have radiator airflow losses. Most of the vehicles were tested with their front windows both open and closed, and the effects of "pop-up" headlights were examined in the tests of the Corvette.

The test runs were made at nominal freestream velocity of 25 m/s (55 mph) and at yaw angles in the range ± 40 degrees. Positive yaw angles were defined as model nose right.

Throughout the test, data from test section ceiling static pressure orifices were acquired for each vehicle to provide the data for computing test section blockage.

SECTION IV

DATA REDUCTION

Six-component external main balance, test section freestream, and support pad pressure data were reduced on-line during the test as well as off-line after the test using a standard FORTRAN reduction program for the on-site Control Data Corporation 1700 computer. Normal wind tunnel corrections accounting for balance interactions, model blockage effects, and freestream flow angularities were applied to the data. Studies of wind tunnel blockage methods show that the conventional area ratio method may undercorrect blockage and buoyancy for bluff bodies such as automobiles because of large wake effects. A method of accounting for the large wake has been derived at Lockheed-Georgia Company by J. E. Hackett and D. J. Wilsden; the method uses the test section ceiling static pressure distribution as described in Reference 2. In the area ratio method, described in Reference 3 (Bettes-Kelly), test section blockage is computed as a ratio of automobile frontal area to test section cross section area, i.e., $K = (S/C)/4$ where S is the automobile frontal area and C is the test section cross section area. The coefficients based on the area ratio method are further corrected by an empirically-derived method to account for the constraints imposed on the flow field about the vehicle by solid tunnel walls. The ceiling pressure signature method (Hackett-Wilsden) utilizes test section static pressures along the ceiling centerline measured both in the presence of the vehicle and in an empty test section. The source/sink distribution which corresponds to the ceiling pressure distribution is inversely calculated; the interference velocities are then inferred from these results. The two methods yield quite similar results for the drag coefficient ($\pm 2\%$ at zero yaw angle depending upon the vehicle), but the area ratio method produced values up to 20% greater for the other coefficients. All data presented in this report was reduced using the pressure signature method (Hackett-Wilsden).

Analysis of pre-run to post-run wind-off-zeros recorded during the test shows the repeatability of the six-component balance loads to be of the following magnitudes:

Component	Load Repeatability	Coefficient Repeatability at 25 m/s
Lift force	± 4.00 N	± 0.0053
Drag force	± 0.36 N	± 0.0004
Pitching moment	± 7.16 N-m	± 0.0032

Component	Load Repeatability	Coefficient Repeatability at 25 m/s
Side force	± 1.20 N	± 0.0016
Yawing moment	± 0.28 N-m	± 0.0001
Rolling moment	± 2.85 N-m	± 0.0012

The wind-off repeatability of all balance components except pitching moment and rolling moment is within the stated balance accuracy presented in Reference 1. The shifts in pitching moment and rolling moment are attributed to small changes in vehicle position relative to the balance, caused by movement of the suspension system and tires.

During the wind-on data runs, three or more data points were recorded at zero degrees yaw angle. The wind-on repeatability of force and moment coefficients is determined by comparison of the zero degree yaw data. The average wind-on repeatability of these runs is tabulated below.

Component	Load Repeatability	Coefficient Repeatability at 25 m/s
Lift force	± 8.14 N	± 0.0108
Drag force	± 1.60 N	± 0.0021
Pitching moment	± 7.43 N-m	± 0.0033
Side force	± 2.31 N	± 0.0030
Yawing moment	± 1.83 N-m	± 0.0008
Rolling moment	± 9.14 N-m	± 0.0041

The coefficient repeatability for both the wind-off and wind-on runs is based on the dimensions of the 1978 Oldsmobile (area = 2.08 m^2 and wheelbase = 2.95 m).

The wind axis moment reference center is coincident with the balance calibration center. The wind tunnel coordinate system is shown in Figure 6.

The balance data are then transferred to the wind axis system at the model moment reference center. The location of the moment reference center relative to the balance center is defined by the values of VDR, HDR, SDR, and DZ1 as shown in Figure 6. The moment reference center is located at the geometric center of the automobile wheels and ground level (tunnel floor). VDR is, therefore, set equal to zero. The values of HDR and SDR are the longitudinal and lateral displacement of the vehicle relative to the balance centerline as measured at the time of installation. DZ1 is the transfer distance from the tunnel floor to the balance moment center and is, of course, independent of the vehicle. All data presented herein is expressed in the stability axis system commonly used in automotive aerodynamics. That is, the drag and side force components are always aligned with the vehicle longitudinal and lateral axes, respectively (i.e., drag is an axial or chord force). The lift force remains perpendicular to the tunnel flow velocity. Vehicle dimensional data are shown in Table 2. Frontal areas were determined by taking long focal-length (1000 mm) pictures from approximately 200 meters (see Figure 7). A planimeter tracing of print enlargements yields an accurate value (within 0.02 m^2). As per industry convention, the area includes the tires, but not appendages such as mirrors, luggage racks, etc.

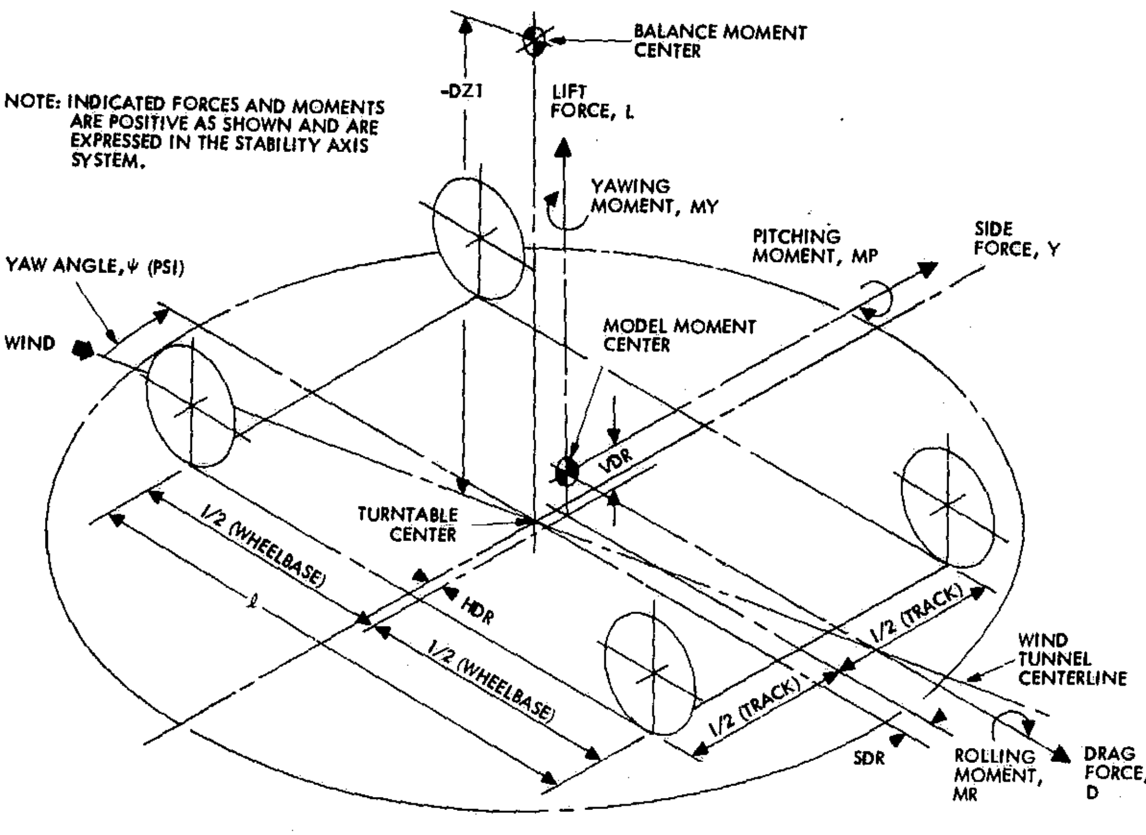


Figure 6. Moment Transfer and Axis System Diagram

Table 2. Model Dimensional Data

Vehicle Name	Otis Van	Chevrolet Chevette 4-Door	Plymouth Horizon 4-Door	AMC Pacer Wagon
Run Number	1	4	8	9
Wheelbase, m	2.4384	2.4765	2.5273	2.5399
Front Area, sq. m	2.5920	1.7650	1.9060	2.2250
Volume, cubic m	6.8260	4.9730	5.8410	7.376
HDR, m	-.0171	-.0050	-.0063	.0027
VDR, m	.0000	.0000	.0000	.0000
SDR, m	.0050	-.0088	.0139	.0076
Front Track, m	1.2954	1.2954	1.4065	1.5544
Rear Track, m	1.2954	1.2954	1.4033	1.5290
Overall Width, m	1.6510	1.5544	1.6764	1.9559
Overall Length, m	3.5052	4.0629	4.0895	4.4196
Overall Height, m	1.8846	1.3411	1.3969	1.3463
Ratio of Roof Length to Overall Length	0.69	0.34	0.35	0.44

Table 2. Model Dimensional Data (Continuation 1)

Vehicle Name	AMC Pacer Sedan	Kaylor GT	GE Centennial	Oldsmobile Delta 88 Sedan
Run Number	10	12	13	15
Wheelbase, m	2.540	2.349	2.337	2.947
Front Area, sq. m	2.222	1.452	1.852	2.077
Volume, cubic m	7.210	4.247	5.643	8.133
HDR. m	.0063	-.0139	-.0082	.0285
VDR, m	.0000	.0000	.0000	.0000
SDR, m	-.0127	-.0171	-.0228	.0184
Front Track, m	1.554	1.448	1.384	1.567
Rear Track, m	1.529	1.397	1.473	1.542
Overall Width, m	1.956	1.728	1.679	1.951
Overall Length, m	4.318	4.167	4.064	5.525
Overall Height, m	1.338	.990	1.362	1.415
Ratio of Roof Length to Overall Height	0.35	0.36	0.43	0.29

Table 2. Model Dimensional Data (Continuation 2)

Vehicle Name	Honda Civic Sedan	Honda Civic Wagon	Energy R&D HEVAN	Ford Fiesta
Run Number	16	18	20	22
Wheelbase, m	2.199	2.281	2.387	2.286
Front area, sq. m	1.630	1.685	3.283	1.747
Volume, cubic m	4.621	5.076	11.40	4.388
HDR, m	.0063	-.0222	.0076	-.0088
VDR, m	.0000	.0000	.0000	.0000
SDR, m	.0018	-.0038	.0222	-.0076
Front Track, m	1.301	1.301	1.524	1.549
Rear Track, m	1.280	1.301	1.562	1.549
Overall Width, m	1.506	1.506	2.133	1.600
Overall Length, m	3.774	4.026	4.635	3.737
Overall Height, m	1.321	1.379	1.930	1.397
Ratio of Roof Length to Overall Height	0.39	0.45	0.71	0.37

Table 2. Model Dimensional Data (Continuation 3)

Vehicle Name	Chevrolet Corvette	CDA Town Car	Sebring-Vanguard Citicar	Zagato Elcar
Run Number	25	29	31	33
Wheelbase, m	2.490	2.032	1.664	1.295
Front Area, sq. m	1.925	1.754	1.700	1.839
Volume, cubic m	6.469	4.848	3.038	3.781
HDR, m	-.0291	-.0018	.0133	-.0231
VDR, m	.0000	.000	.000	.000
SDR, m	-.0038	.0133	.0079	-.0066
Front Track, m	1.50	1.311	1.105	1.143
Rear Track, m	1.499	1.314	1.105	1.143
Overall Width, m	1.765	1.524	1.392	1.346
Overall Length, m	4.420	3.683	2.403	2.134
Overall Height, m	1.321	1.384	1.511	1.613
Ratio of Roof Length to Overall Length	0.18	0.40	0.34	0.50

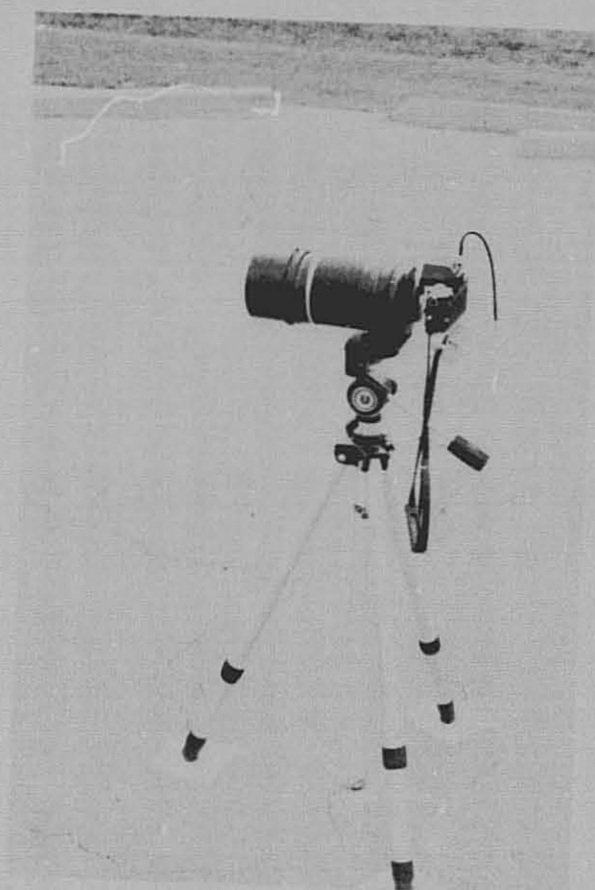


Figure 7. Photographic Setup Required to Accurately Determine Frontal Areas. Print enlargements were subsequently integrated with a planimeter yielding an accurate frontal area measurement.

SECTION V

RESULTS

A. DATA PRESENTATION

Thirty-four vehicle configurations were investigated in the course of the testing (see Appendix B, Table B-1). Table 3 presents a brief summary of the zero-yaw drag levels of all 16 vehicles in their "standard" configurations. When the drag-yaw characteristics are considered, the relative ordering may change (accounting for ambient winds will be discussed later).

The complete six-component data set generated during this study is presented in Appendix B. Both tabular (Appendix B, Part I) and graphical (Appendix B, Part II) formats are included. Although drag is the component of primary interest, the other components are important for dynamic analyses.

Table 3. Zero-Yaw Drag Coefficient and Frontal Area of Several Electric Hybrid and Subcompact IC Engine Vehicles - Windows Closed and Radiators Blocked Where Appropriate*

Vehicle	CD_0	A, m^2	CD_0A, m^2
Otis Van	0.581	2.593	1.507
Chevrolet Chevette	0.502	1.765	0.886
Plymouth Horizon	0.411	1.906	0.783
AMC Pacer Wagon	0.406	2.225	0.903
AMC Pacer Sedan	0.450	2.222	1.000
Kaylor GT	0.583	1.359	0.792
GE Centennial	0.337	1.851	0.624
Oldsmobile Delta 88 Sedan	0.558	2.077	1.159
Honda Civic Sedan	0.503	1.630	0.820
Honda Civic Wagon	0.514	1.685	0.866
Energy R&D HEVAN	0.497	3.283	1.632
Ford Fiesta	0.468	1.747	0.818

Vehicle	CD_0	A, m^2	CD_0A, m^2
Chevrolet Corvette	0.490	1.925	0.943
CDA Town Car	0.367	1.754	0.644
Sebring-Vanguard Citicar	0.541	1.700	0.920
Zagato Elcar	0.490	1.838	0.901

*All IC engine vehicles had their grilles covered since an electric version would not have a radiator airflow requirement and the resulting drag. The Oldsmobile Delta 88, however, represented the National Motors Gemini II parallel hybrid vehicle, which retains the standard cooling system.

B. OBSERVATIONS

It is difficult to make universal statements about the data since, in automotive aerodynamics, broad generalizations usually prove to be unreliable. There are many subtle details characteristic of each vehicle which affect the local flow conditions and hence, the forces and moments. To state that vehicles of a particular class all exhibit predictable aerodynamic traits is risky at best. Nevertheless, certain features characteristic of this data base will be highlighted in what follows. In addition, a simplified procedure for accurately determining the effects of statistically varying ambient winds on a vehicle's drag is presented in Appendix C.

Asymmetry

A brief visual review of the graphical format data will quickly convince the reader that' the lift, pitching moment, and drag coefficients are usually not symmetrical about the zero-yaw point as one might expect. If this were a result merely of wind tunnel flow angularity, the origin would be shifted slightly, but the symmetry would still exist; this is clearly not the case. Hence, it is concluded that the vehicles themselves are somewhat asymmetrical. Upon closer examination, it was noted that there was significant asymmetry on most vehicle underbodies as well as a non-zero static and wind loaded roll attitude. Some vehicles also had asymmetrical side view mirror systems.

Yaw Angle

Despite the asymmetry, the drag-yaw characteristic has certain similarities for all vehicles. The minimum drag occurs at or near the zero-yaw point, increases rapidly to a maximum level at a yaw angle of about 20 to 40 degrees, and then falls off just as rapidly beyond that point. The yaw characteristic is of interest because vehicles usually perform under some ambient wind condition and are therefore operating at an angle of yaw. This condition increases the vehicle's effective drag and should be considered when evaluating the aerodynamic road load contribution. A rigorous and statistically accurate procedure was developed to quantify these effects (Reference 4). Subsequently, linearizing assumptions were adopted which greatly simplified application of the procedure (Reference 5). Using this approach, the only necessary parameters are the vehicle speed (or driving cycle), the annual mean wind speed (assumed equally probable from any direction), and the ratio of the maximum drag coefficient (occurs at around 20 to 40 degrees of yaw) to the zero-yaw coefficient (CD_{max} ratio). Further discussion on the implementation of this procedure in vehicle computer simulators, or applying it to data such as is contained herein, is presented in Appendix C. As an example, Table 4 presents an effective wind-weighted drag coefficient, CD_{eff}, for these test vehicles. In this case the wind was assumed to be the national annual mean wind speed (12 kph) and the vehicles were assumed to be operating over the J227a D cycle. As can be seen, the wind-weighting factor (F) averaged 3½%, ranging from less than 2% to over 6%. Had this analysis been performed for a "B" cycle, the factor would be as high as 44%. (The wind vector is more of a factor at lower vehicle speeds; however, the aerodynamic component is a smaller portion of the total energy requirements.)

Table 4. Effective Wind-Weighted Drag of Test Vehicles Performing J227a D Cycles in the Presence of a 12 kph Annual Mean Wind Speed Equally Probable From Any Direction (Windows Closed)

Vehicle	CD_0	CD_{max}/CD_0	F	CD_{eff}	$CD_{eff}A$, m^2
Otis Van	0.581	1.30	1.043	0.606	1.571
Chevrolet Chevette	0.502	1.14	1.023	0.514	0.907
Plymouth Horizon	0.411	1.32	1.045	0.429	0.818
AMC Pacer Wagon	0.406	1.27	1.039	0.422	0.939
AMC Pacer Sedan	0.450	1.24	1.035	0.466	1.035
Kaylor GT	0.583	*		—	—
GE Centennial	0.337	1.12	1.020	0.344	0.637
Oldsmobile Delta 88 Sedan	0.558	1.46	1.063	0.593	1.232
Honda Civic Sedan	0.503	1.28	1.040	0.523	0.852
Honda Civic Wagon	0.514	1.22	1.033	0.531	0.895

Vehicle	CD_0	CD_{max}/CD_0	F	CD_{eff}	$CD_{eff}A$, m^2
Energy R&D HEVAN	0.497	*		——	——
Ford Fiesta	0.468	1.22	1.033	0.483	0.844
Chevrolet Corvette	0.490	1.10	1.018	0.499	0.961
CDA Town Car	0.367	1.16	1.025	0.376	0.660
Sebring-Vanguard Citicar	0.541	1.20	1.030	0.557	0.947
Zagato Elcar	0.490	1.37	1.051	0.515	0.947

* Maximum CD was not determined since test yaw angle was limited to 20 degrees.

The average CD_{max} ratio for the vehicles listed in Table 4 is about 1.25 with windows closed and 1.45 with windows open. No simple relationship could be found between this ratio and the vehicles zero-yaw drag level. That is, one might expect that the lowest drag vehicles may have their tenuous flow attachment disrupted more abruptly and with greater consequence as the yaw angle increased, thus resulting in the larger CD_{max} ratios. Such is not the case with these data, nor is the converse true; no simple correlation is apparent.

Windows Open/Closed

Because of their current limited energy capacity, electric vehicles will not immediately be able to afford the luxury of an active air conditioning system; it is therefore reasonable to expect that they will be operated in a windows-open configuration over a significant portion of their lifetime. As previously discussed, open windows adversely affect the slope and ultimate magnitude of the drag-yaw curves. Curiously, open windows may or may not increase the drag at zero-yaw angle. In fact, four vehicles (Honda Civic Sedan and Wagon, HEVAN, and the Chevrolet Corvette) actually had a lower zero-yaw drag with their front windows open than when closed (almost 4% lower on the Civic wagon). This situation was previously observed while performing precision coast-down testing on a 1975 Chevrolet Impala (Reference 6). Although they reported this result, the authors were uncomfortable with it, and desired further investigation. The present data seems to confirm that the circumstance can and does occur. However, it should be noted that a vehicle operates at some angle of yaw over most of its lifetime; therefore, the effect of open window operation is a net increase in the vehicle's drag. Had a wind weighting analysis similar to that of Table 4 been performed on these vehicles with open windows, the average wind weighting factor, F, would increase from 3½% to almost 6% over a J227a D cycle.

Ground Clearance

There is a natural boundary layer (velocity gradient) growth along the wind tunnel floor resulting in a thickness of about 15 cm (6 in.) at the test section midpoint for the Lockheed-Georgia wind tunnel. Since several of the short wheel base vehicles had to be mounted on raised/cantilevered plates (approximately 3 cm above the floor), a brief check was made to quantify the effect. The Chevette had a wheelbase length which made it possible to mount it either on the flush balance pads or on the cantilevered plates. Tests were performed in both positions (Runs 4 and 6 respectively) with all other parameters unchanged. The effect of raising the vehicle was to increase the drag by from 1% to 2% over the entire yaw range. Certainly, one would expect there to be some increase since the vehicle is moving further out into the undisturbed freestream flow. It is believed that the effect observed with the Chevette is probably typical for the other vehicles tested on the cantilevered plates. It should be noted, however, that the data presented for these vehicles have not been corrected for this effect. The vehicles are: (1) Honda Civic Sedan, (2) Honda Civic Wagon, (3) Ford Fiesta (here the mounting procedure resulted in only a 1½ cm elevation and the effect is expected to be less than 1%), (4) CDA Town Car, (5) Sebring-Vanguard Citicar, and (6) the Zagato Elcar.

Radiator Airflow

It has long been recognized that, for conventional automobiles, radiator airflow is a major source of aerodynamic drag. A great deal of effort has gone into developing designs which accomplish the engine cooling task while minimizing the detrimental aerodynamic effects (References 7,8, and 9). An all-electric vehicle, however, does not have a motor cooling requirement and therefore should possess a basic advantage in this respect. In an effort to quantify the benefit, two vehicles (the Chevette and the Corvette) were tested with their radiators both open to airflow and blocked. The blocking was accomplished by simply covering the grille, and other radiator inlet areas, with flexible sheet plastic held firmly in place with duct tape; all related body contours remained undisturbed. The Chevette with an open radiator (Run 7) exhibited about 7-8% higher drag than when the radiator was blocked (Run 4). This increment was approximately constant across the yaw range, but the asymmetry was exaggerated with the open radiator. The Corvette had a 6½% drag increase (Run 28) when open compared to blocked (Run 25); this comparison, however, was made at zero yaw only. It is anticipated that the radiator drag increment might be different for each vehicle, and had time permitted, this would have been investigated. In summary, however, if an IC engine vehicle were converted to electric power and the radiator airflow were eliminated, one could expect a drag benefit of from 5 to 10%.

Pop-Up Headlights

Since the current federal safety standards prevent covering headlights with transparent (plastic) body fairings, the designer is faced with a dilemma: either accept the drag penalty of unfaired headlights (3-5%) or provide a movable system of some sort (pop-up sliding doors, etc.).

The second option usually provides some drag benefit during daytime operation, but a significant penalty at night when the headlights must be operational. The Corvette was equipped with such a pop-up headlight feature and the drag increment (at zero-yaw) was found to be about 3% in the functional position (Run 27). Significantly higher penalties (up to 6%) have been observed on other vehicles (References 10 and 11). This is due to the importance and quality of the local air flow. That is, very low-drag vehicles rely heavily on clean front-end airflow; if this is severely disturbed by unfaired headlights, the penalty can be much greater.

In the case of a vehicle of relatively high drag coefficient, such as the Corvette tested, the penalty is less severe.

General

The actual mechanisms leading to automotive aerodynamic forces and moments are not well understood. Airflow around the automobile is characterized by ground interference and large areas of separated and vortex flow. Unlike aircraft aerodynamics, automobile aerodynamics is largely unresponsive to classical analytical treatment. It has therefore become a rather empirical science, relying heavily on development through wind tunnel test techniques. A more complete treatment of general aerodynamic design principles and automotive drag prediction procedures is presented in Reference 5.

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APPENDIX A

BRIEF DESCRIPTION OF AERODYNAMIC FORCE AND MOMENT COEFFICIENTS

The aerodynamic forces generated by a road vehicle as it moves through the air may be resolved into an orthogonal set of three forces and three moments (see Figure 6). It is desirable to nondimensionalize these forces and moments so that they will be independent of vehicle size (scale) and a function of vehicle shape only.*

The six force and moment coefficients are mathematically defined (according to industry convention) in the table below.

Force or Moment	Coefficient	Equation**
Drag force, D	CD	CD = D/QA
Lift force, L	CL	CL = L/QA
Side force, Y	CY	CY = Y/QA
Pitching moment, MP	CM	CM = MP/QAℓ
Yawing moment, MY	CN	CN = MY/QAℓ
Rolling moment, MR	CR	CR = MR/QAℓ

*It should be noted that true aerodynamic similarity is not produced unless the airflow Reynolds number, $\rho v \ell / \mu$, is also matched; this normally requires wind tunnel testing of 1/4-scale models at four times their full scale speed. In practice, however, aerodynamic forces on bluff bodies, such as road vehicles, show little sensitivity to Reynolds number variations and the effect is often neglected; this can cause problems, however, since airflow in localized areas may be quite dependent and could trigger major flow regime (separated vs non-separated) dissimilarities unless matched.

**Q is the tunnel dynamic pressure (1/2 x air density x air velocity squared); A is the vehicle's projected cross sectional area including wheels and excluding appendages such as mirrors, roof racks, antennas etc.; and ℓ is the vehicle wheelbase. The units are arbitrary as long as they are constant and combine to be nondimensional.

Unlike high-speed sports and competition vehicles which rely heavily on aerodynamic forces for such things as traction and stability, the conventional road vehicle is primarily concerned with the drag component. This is not to say that the other five aerodynamic components are not of interest, but unless unusual operational conditions are anticipated, low drag optimization is usually pursued without compromise. Aerodynamic influences on stability and directional control during passing and from side gusts do, however, merit some examination, especially for the case of large side-area delivery vehicles (vans) where the side loading can be quite significant. Basically, one desires to have the aerodynamic center of pressure behind the vehicle's center of gravity for "weathercock" or directional stability and for pitch stability. The side force center of pressure (cp) longitudinal location can be simply calculated by dividing the yawing moment coefficient (CN) by the side force coefficient (CY). The resulting value is the center of pressure location relative to the moment center (mid-wheelbase for these data) in "wheelbases". That is, a quotient of +0.1 means that the side force cp is 0.1 wheelbase units forward of the wheelbase midpoint. With knowledge of the center of gravity location, one may determine the vehicle's aerodynamic directional stability. Pitch stability may be similarly calculated by dividing the pitching moment (MP) by the lift force (L).

It should be pointed out that the foregoing discussion refers only to the static stability. Dynamic stability due to unsteady aerodynamic forces coupled with the dynamic response of the vehicle's suspension system, requires a much more complex analysis, one that is beyond the scope of this report. The more interested reader is directed to publications such as <u>Transient Aerodynamic Forces and Moments on Models of Vehicles Passing Through Cross-Wind</u> by Yoshida, Yasushi, et al. (SAE Paper 770391, Feb. 1977) and <u>Transient Nature of Wind Gust Effects on Automobiles</u> by F. N. Beauvais (SAE Paper 670608, 1967).

APPENDIX B

COMPLETE DATA (TABULAR AND GRAPHICAL FORMATS)

Thirty-four vehicle configurations were investigated in the course of the testing (see Table B-1). The complete six-component data set generated during this study is presented herein, in both tabular and graphical formats.

Tabular Format

In the tabular format (see Part I) each run is characterized by a configuration description in which items are listed in the following order:

(1) Run number.

(2) Vehicle name (and year if a production car).

(3) Radiator configuration (either open or blocked to airflow - NA signifies the absence of a radiator altogether).

(4) Side window configuration (either all closed or front windows open - some vehicles were equipped with fore and aft sliding windows rather than rolldown).

(5) Mounting configuration. (All vehicles with wheelbases greater than 2.29 m could utilize the standard flush wheel balance pads. Shorter vehicles were mounted on a cantilevered plate which elevated them as indicated in Figure 5; the resulting displacement above the tunnel floor is given in inches.)

(6) Wheelbase and (directly below) the frontal area, in feet and square feet, respectively. These were used to nondimensionalize the moment and force data into coefficient form.

(7) Yaw angle, ψ (PSI).

(8) Tunnel dynamic pressure, Q0, in lb/ft^2.

(9) Values of the normal six component coefficients, listed as functions of yaw angle; the lift coefficient is further resolved into its front and rear wheel components. The coefficients are identified as follows: CD - drag; CL - lift; CLF - lift on front wheels; CLR - lift on rear wheels; CM - pitching moment; CY - side force; CN - yawing moment; CR - rolling moment. Further description and the coefficient equations are presented in Appendix A.

Table B-1. Run Index

Date	Run No.	Vehicle	Configuration Radiator[1]	Windows[2]	Mount	Yaw[3]
7-5-78	1	Otis Van	NA	C	Flush	A
7-5-78	2	Otis Van	NA	0	Flush	A
7-5-78	3	Otis Van	NA	0	Flush	C
7-5-78	4	Chevy Chevette	B	C	Flush	A
7-5-78	5	Chevy Chevette	B	0	Flush	A
7-5-78	6	Chevy Chevette	B	C	+3 cm	A
7-6-78	7	Chevy Chevette	0	C	Flush	A
7-6-78	8	Plymouth Horizon	B	C	Flush	A
7-6-78	9	AMC Pacer Wagon	B	C	Flush	A
7-6-78	10	AMC Pacer Wagon	B	C	Flush	A
7-6-78	11	AMC Pacer Sedan	B	0	Flush	A
7-6-78	12	Kaylor G. T.	NA	NA	Flush	C
7-6-78	13	GE Centennial	NA	C	Flush	C
7-6-78	14	GE Centennial	NA	0	Flush	C
7-7-78	15	Olds Delta 88	0	C	Flush	C
7-7-78	16	Honda Civic Sedan	B	C	+3 cm	C
7-7-78	17	Honda Civic Sedan	B	0	+3 cm	C
7-7-78	18	Honda Civic Wagon	B	C	+3 cm	C
7-7-78	19	Honda Civic Wagon	B	0	+3 cm	C
7-7-78	20	HEVAN	NA	C	Flush	D
7-7-78	21	HEVAN	NA	0	Flush	D
7-7-78	22	Ford Fiesta	B	C	+1.5 cm	A
7-7-78	23	Ford Fiesta	B	0	+1.5 cm	A
7-8-78	25	'67 Corvette	B	C	Flush	A
7-8-78	26	'67 Corvette	B	0	Flush	A
7-8-78	27	'67 Corvette[4]	B	C	Flush	E
7-8-78	28	'67 Corvette	0	C	Flush	E
7-8-78	29	CDA Town Car	NA	C	+ 3 cm	A
7-8-78	30	CDA Town Car	NA	0	+ 3 cm	A
7-8-78	31	Sebring Citicar	NA	C	+ 3 cm	A
7-8-78	32	Sebring Citicar	NA	0	+ 3 cm	A
7-8-78	33	Zagato Elcar	NA	C	+ 3 cm	A
7-8-78	34	Zagato Elcar	NA	0	+ 3 cm	A

1. NA - Vehicle not equipped with a radiator; B - Radiator flow path blocked; 0 - Radiator flow path open
2. C - All windows closed; 0 - Two front windows open
3. Yaw schedules:

   A - (±) 0, 3, 6, 9, 12, 16, 20, 30, 40
   B - (±) 0, 3, 6, 9, 12, 16, 20, 30
   C - (±) 0, 3, 6, 9, 12, 16, 20
   D - (±) 0, 3, 6, 9, 12, 15,
   E - (±) zero only

4. Headlights in operational position.

Graphic Format

In Part II of this appendix the tabular data just discussed is presented, for each vehicle, in the form of two pages of plots: first page - lift, pitching moment, and drag coefficients versus yaw angle; second page - side force, yawing, and rolling moment versus yaw angle.

The symbol legend in the upper left-hand corner of each page provides configuration specifications similar to those in Table B-1 (note that the dynamic pressure is listed as Q rather than QO since here it is an average over the entire run).

PART I: TABULAR FORMAT

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LOCKHEED-GEORGIA COMPANY LOW SPEED WIND TUNNEL

1978 EHV DATA BASE REDUCTION METHOD: HACKETT-WILSDEN

REPORT LSWT 291
MODEL JPL
DATE 8-14-78

RUN	CONFIGURATION DESCRIPTION	WHEELBASE AREA	PSI (DEG)	QD (PSF)	CD	CL	CLF	CLR	CM	CY	CN	CR	
1	OTIS VAN RADIATOR N.A. , WINDOWS CLOSED, FLUSH	8.00	-40	9.75	.6710	.449	.531	-.082	.307	-1.57	-.102	-.611	
		27.91	-30	9.13	.7541	.316	.493	-.177	.335	-1.36	-.080	-.541	
			-20	8.58	.7071	.221	.411	-.190	.300	-1.07	-.110	-.426	
			-16	8.54	.6969	.194	.390	-.196	.293	-.911	-.095	-.373	
			-13	8.38	.6835	.164	.366	-.202	.284	-.740	-.079	-.306	
			-12	8.35	.6750	.150	.353	-.203	.278	-.688	-.077	-.291	
			-9	8.28	.6536	.137	.339	-.202	.270	-.529	-.072	-.228	
			-6	8.24	.6325	.117	.324	-.207	.265	-.352	-.052	-.157	
			-3	8.22	.6181	.094	.303	-.208	.255	-.131	-.027	-.056	
			0	8.19	.5813	.068	.258	-.190	.224	.048	.003	.020	*
			3	8.15	.5902	.099	.295	-.195	.245	.249	.034	.087	
			6	8.20	.6097	.118	.310	-.192	.251	.428	.061	.161	
			9	8.29	.6292	.149	.327	-.179	.253	.581	.080	.227	
			12	8.32	.6354	.183	.356	-.173	.265	.741	.094	.302	
			16	8.50	.6543	.220	.386	-.166	.276	.920	.085	.372	
			20	8.68	.6661	.245	.400	-.155	.277	1.062	.095	.423	
			30	9.07	.7522	.303	.470	-.167	.318	1.419	.078	.558	
2	OTIS VAN RADIATOR N.A. , WINDOWS OPEN , FLUSH	8.00	-40	9.71	.6924	.474	.559	-.084	.322	-1.57	-.094	-.615	
		27.91	-35	9.40	.7452	.415	.542	-.126	.334	-1.46	-.089	-.575	
			-30	9.11	.7713	.328	.504	-.176	.340	-1.32	-.075	-.524	
			-25	8.91	.7582	.239	.447	-.208	.328	-1.21	-.064	-.485	
			-20	8.76	.7158	.198	.400	-.202	.301	-1.05	-.093	-.421	
			-16	8.66	.7044	.183	.383	-.200	.292	-.838	-.078	-.349	
			-12	8.54	.6811	.141	.347	-.205	.276	-.622	-.050	-.270	
			-9	8.50	.6639	.119	.326	-.207	.266	-.483	-.039	-.214	
			-6	8.45	.6573	.105	.311	-.206	.259	-.307	-.021	-.140	
			-3	8.28	.6261	.091	.298	-.206	.252	-.118	-.017	-.063	
			0	8.29	.5778	.073	.265	-.192	.229	.051	.001	.023	*
			2	8.24	.6028	.085	.284	-.199	.242	.239	.017	.084	
			6	8.30	.6161	.103	.294	-.191	.243	.408	.039	.156	
			9	8.36	.6417	.129	.314	-.185	.250	.569	.050	.224	
			12	8.46	.6601	.140	.324	-.184	.254	.727	.058	.284	
			16	8.58	.6886	.163	.350	-.187	.268	.906	.066	.353	
			20	8.81	.7261	.170	.371	-.201	.286	1.046	.039	.407	
			26	8.98	.6962	.278	.433	-.154	.293	1.230	.091	.480	
			30	9.41	.7524	.294	.464	-.170	.317	1.339	.070	.525	

LOCKHEED-GEORGIA COMPANY LOW SPEED WIND TUNNEL

1978 EHV DATA BASE REDUCTION METHOD: HACKETT-WILSDEN

REPORT LSWT 291
MODEL JPL
DATE 8-14-78

RUN	CONFIGURATION DESCRIPTION	WHEELBASE AREA	PSI (DEG)	QO (PSF)	CD	CL	CLF	CLR	CM	CY	CN	CR	
3	OTIS VAN RADIATOR N.A. , WINDOWS OPEN , FLUSH WIPER BLADES OFF	8.00	-22	8.84	.7381	.210	.408	-.198	.303	-1.12	-.063	-.427	
		27.91	-20	8.66	.7210	.208	.402	-.194	.298	-1.06	-.096	-.407	
			-16	8.56	.7103	.190	.385	-.195	.290	-.859	-.080	-.339	
			-12	8.54	.6881	.143	.346	-.202	.274	-.626	-.053	-.257	
			-9	8.45	.6675	.124	.324	-.201	.263	-.490	-.042	-.203	
			-6	8.26	.6632	.103	.308	-.204	.256	-.324	-.023	-.140	
			-3	8.29	.6328	.094	.299	-.205	.252	-.130	-.019	-.065	
			0	8.25	.5822	.082	.272	-.189	.231	.047	.000	.018	*
			3	8.18	.6091	.085	.285	-.199	.242	.236	.015	.087	
			6	8.31	.6300	.102	.292	-.190	.241	.399	.031	.155	
			9	8.38	.6513	.135	.322	-.187	.254	.565	.047	.221	
			12	8.47	.6687	.144	.327	-.183	.255	.714	.052	.278	
			16	8.62	.6952	.168	.354	-.185	.269	.905	.064	.346	
			20	8.84	.7265	.172	.370	-.198	.281	1.052	.043	.404	
4	1978 CHEVETTE 4 DR. RADIATOR BLOCKED, WINDOWS CLOSED, FLUSH	8.13	-40	8.40	.5440	.316	.300	.015	.142	-1.69	-.119	-.416	
		19.00	-30	8.18	.5755	.567	.360	.207	.076	-1.38	-.164	-.323	
			-20	8.09	.5670	.346	.202	.144	.028	-.878	-.143	-.208	
			-16	7.98	.5644	.252	.125	.127	-.000	-.712	-.116	-.169	
			-12	7.90	.5387	.238	.071	.167	-.048	-.539	-.088	-.130	
			-9	7.95	.5208	.247	.052	.194	-.070	-.397	-.068	-.099	
			-6	7.78	.5178	.391	.080	.310	-.115	-.235	-.053	-.070	
			-3	7.87	.5073	.379	.054	.324	-.135	-.117	-.027	-.039	
			0	7.93	.5016	.411	.072	.339	-.134	.008	-.001	-.002	*
			3	7.91	.4926	.377	.071	.305	-.117	.128	.028	.014	
			6	7.88	.4948	.267	.066	.200	-.066	.283	.048	.046	
			9	7.90	.5138	.251	.078	.173	-.047	.422	.071	.076	
			12	7.94	.5353	.270	.103	.167	-.032	.558	.094	.110	
			16	7.98	.5574	.291	.146	.145	.000	.732	.117	.153	
			20	8.11	.5664	.359	.196	.163	.016	.902	.134	.197	
			30	8.26	.5596	.462	.312	.150	.081	1.398	.151	.313	
			40	8.61	.5301	.326	.280	.046	.117	1.688	.110	.406	

LOCKHEED-GEORGIA COMPANY LOW SPEED WIND TUNNEL

1978 EHV DATA BASE   REDUCTION METHOD: HACKETT-WILSDEN

REPORT LSWT 291
MODEL JPL
DATE 8-14-78

RUN	CONFIGURATION DESCRIPTION	WHEELBASE AREA	PSI (DEG)	QO (PSF)	CD	CL	CLF	CLR	CM	CY	CN	CR	
5	1978 CHEVETTE 4 DR. RADIATOR BLOCKED, WINDOWS OPEN , FLUSH	8.13	-40	8.45	.6893	.336	.373	-.037	.206	-1.55	-.074	-.384	
		19.00	-30	8.39	.7177	.274	.288	-.013	.151	-1.19	-.085	-.279	
			-20	8.18	.6739	.301	.178	.122	.028	-.755	-.088	-.179	
			-16	8.10	.6276	.233	.102	.131	-.014	-.614	-.076	-.142	
			-12	7.95	.5744	.274	.072	.202	-.064	-.435	-.073	-.111	
			-9	7.98	.5435	.287	.060	.226	-.082	-.329	-.057	-.090	
			-6	7.94	.5179	.308	.053	.255	-.101	-.214	-.038	-.060	
			-3	7.93	.5075	.347	.049	.297	-.124	-.115	-.021	-.031	
			0	7.89	.5011	.358	.056	.301	-.122	.002	-.003	-.000	*
			3	7.97	.4952	.312	.049	.263	-.106	.117	.018	.019	
			6	7.92	.5096	.280	.060	.220	-.079	.222	.044	.042	
			9	8.01	.5474	.283	.074	.208	-.066	.337	.059	.075	
			12	7.97	.5919	.327	.102	.225	-.061	.439	.080	.098	
			16	8.06	.6508	.379	.148	.231	-.041	.585	.095	.137	
			20	8.21	.6691	.327	.190	.137	.026	.794	.084	.185	
			30	8.48	.7066	.269	.272	-.002	.137	1.226	.076	.295	
			40	8.65	.6613	.328	.356	-.028	.192	1.566	.059	.395	
6	1978 CHEVETTE 4 DR. RADIATOR BLOCKED, WINDOWS CLOSED,1" PAD	8.13	-40	8.59	.5468	.328	.303	.024	.134	-1.71	-.118	-.406	
		19.00	-30	8.36	.5936	.549	.349	.200	.068	-1.37	-.156	-.305	
			-20	8.06	.5829	.337	.194	.143	.019	-.888	-.139	-.204	
			-16	8.06	.5770	.253	.124	.129	-.008	-.728	-.110	-.166	
			-12	8.00	.5528	.219	.064	.155	-.050	-.556	-.084	-.127	
			-9	7.98	.5307	.233	.044	.188	-.077	-.412	-.066	-.100	
			-6	7.88	.5282	.371	.071	.299	-.119	-.257	-.052	-.073	
			-3	7.87	.5183	.364	.053	.311	-.134	-.126	-.026	-.038	
			0	7.94	.5131	.386	.066	.320	-.132	.000	-.002	-.003	*
			3	7.93	.5090	.364	.065	.298	-.121	.126	.028	.018	
			6	7.89	.5112	.250	.053	.197	-.077	.282	.047	.049	
			9	7.94	.5285	.233	.067	.166	-.054	.424	.069	.080	
			12	8.01	.5534	.258	.083	.174	-.051	.556	.091	.114	
			16	8.02	.5705	.284	.127	.157	-.020	.743	.116	.157	
			20	8.08	.5830	.309	.176	.132	.016	.906	.134	.195	
			30	8.35	.5795	.473	.308	.165	.065	1.408	.149	.315	
			40	8.69	.5405	.357	.286	.071	.102	1.717	.114	.412	

LOCKHEED-GEORGIA COMPANY LOW SPEED WIND TUNNEL

1978 EHV DATA BASE   REDUCTION METHOD: HACKETT-WILSDEN

REPORT LSWT 291
MODEL   JPL
DATE   8-14-78

RUN	CONFIGURATION DESCRIPTION	WHEELBASE AREA	PSI (DEG)	QO (PSF)	CD	CL	CLF	CLR	CM	CY	CN	CR	
7	1978 CHEVETTE 4 DR. RADIATOR OPEN , WINDOWS CLOSED, FLUSH	8.13	-40	8.66	.5606	.466	.414	.051	.181	-1.66	-.123	-.394	
		19.00	-30	8.29	.6125	.514	.387	.126	.130	-1.32	-.151	-.302	
			-20	8.17	.5998	.429	.288	.141	.073	-.880	-.140	-.200	
			-16	8.11	.5924	.355	.232	.123	.054	-.723	-.120	-.165	
			-12	8.00	.5649	.329	.184	.145	.019	-.548	-.102	-.128	
			-9	7.93	.5449	.348	.166	.182	-.008	-.397	-.083	-.099	
			-6	8.02	.5495	.456	.172	.283	-.055	-.226	-.067	-.061	
			-3	8.01	.5383	.429	.157	.272	-.057	-.108	-.036	-.036	
			0	8.00	.5404	.435	.157	.278	-.060	.005	-.000	-.002	*
			3	7.96	.5327	.426	.159	.267	-.053	.117	.042	.011	
			6	8.01	.5168	.315	.162	.153	.004	.290	.065	.048	
			9	7.96	.5340	.334	.182	.152	.015	.419	.090	.076	
			12	8.01	.5524	.329	.205	.124	.040	.575	.107	.115	
			16	8.16	.5829	.372	.252	.120	.065	.738	.120	.152	
			20	8.14	.5936	.443	.318	.125	.096	.913	.137	.198	
			30	8.36	.5921	.441	.380	.060	.160	1.368	.148	.311	
			40	8.66	.5732	.451	.421	.029	.196	1.666	.110	.397	
8	1978 HORIZON 4 DR., RADIATOR BLOCKED, WINDOWS CLOSED, FLUSH	8.29	-40	8.54	.5212	.402	.384	.018	.183	-1.47	-.129	-.355	
		20.52	-30	8.27	.5742	.218	.226	-.007	.117	-1.21	-.158	-.285	
			-20	8.17	.5423	.319	.217	.102	.057	-.887	-.133	-.213	
			-16	7.97	.5367	.320	.183	.137	.023	-.724	-.115	-.185	
			-12	8.07	.5380	.342	.145	.196	-.025	-.549	-.093	-.142	
			-9	8.03	.4862	.225	.098	.126	-.013	-.412	-.073	-.112	
			-6	8.04	.4345	.075	.040	.035	.002	-.271	-.048	-.072	
			-3	8.09	.4153	.018	.024	-.005	.014	-.132	-.024	-.041	
			0	7.99	.4109	-.017	-.002	-.015	.006	.010	-.000	-.002	*
			3	7.93	.4113	-.000	.012	-.012	.012	.149	.028	.019	
			6	8.01	.4238	.057	.030	.027	.001	.289	.051	.053	
			9	8.01	.4751	.227	.094	.132	-.019	.413	.073	.088	
			12	8.18	.5191	.334	.137	.197	-.029	.545	.092	.130	
			16	8.03	.5277	.424	.205	.219	-.006	.707	.117	.171	
			20	8.16	.5108	.289	.193	.096	.047	.893	.130	.212	
			30	8.42	.5136	.179	.189	-.010	.100	1.257	.157	.302	
			40	8.73	.4760	.297	.295	.002	.146	1.479	.125	.360	

LOCKHEED-GEORGIA COMPANY LOW SPEED WIND TUNNEL

1978 EHV DATA BASE REDUCTION METHOD: HACKETT-WILSDEN

REPORT LSWT 291
MODEL JPL
DATE 8-14-78

RUN	CONFIGURATION DESCRIPTION	WHEELBASE AREA	PSI (DEG)	QO (PSF)	CD	CL	CLF	CLR	CM	CY	CN	CR	
9	1978 PACER WAGON RADIATOR BLOCKED, WINDOWS CLOSED, FLUSH	8.33	-40	8.61	.4749	.739	.516	.223	.147	-1.24	-.102	-.289	
		23.95	-30	8.37	.4760	.842	.515	.327	.093	-1.16	-.073	-.264	
			-20	8.14	.5231	.675	.349	.326	.011	-.783	-.072	-.181	
			-16	8.09	.5279	.547	.265	.282	-.008	-.599	-.073	-.135	
			-12	8.09	.4915	.396	.203	.193	.005	-.454	-.065	-.096	
			-9	8.08	.4503	.252	.157	.095	.030	-.338	-.058	-.070	
			-6	8.01	.4287	.177	.133	.044	.044	-.194	-.051	-.039	
			-3	8.02	.4122	.134	.106	.027	.038	-.082	-.030	-.018	
			0	8.01	.4060	.101	.079	.021	.028	.016	-.004	.004	*
			3	8.02	.4108	.107	.093	.013	.039	.125	.023	.016	
			6	8.00	.4261	.140	.118	.022	.047	.232	.039	.036	
			9	8.03	.4559	.267	.147	.120	.013	.356	.051	.066	
			12	8.06	.4907	.391	.182	.209	-.013	.452	.067	.092	
			16	8.13	.5099	.511	.237	.274	-.018	.603	.073	.124	
			20	8.16	.4953	.625	.319	.307	.005	.765	.078	.168	
			30	8.39	.4468	.708	.449	.259	.094	1.145	.067	.262	
			40	8.65	.4467	.694	.467	.227	.120	1.249	.085	.311	
10	1978 PACER SEDAN RADIATOR BLOCKED, WINDOWS CLOSED, FLUSH	8.33	-40	8.54	.5670	.959	.539	.420	.059	-.927	-.183	-.243	
		23.92	-30	8.18	.5576	1.030	.544	.486	.029	-.755	-.178	-.199	
			-20	8.07	.5587	.823	.389	.435	-.023	-.474	-.147	-.128	
			-16	7.99	.5419	.697	.310	.387	-.038	-.365	-.132	-.100	
			-12	7.95	.5140	.582	.248	.334	-.043	-.269	-.108	-.070	
			-9	7.94	.4888	.501	.212	.289	-.038	-.219	-.081	-.056	
			-6	7.90	.4715	.431	.181	.250	-.034	-.151	-.055	-.040	
			-3	7.92	.4548	.374	.160	.214	-.027	-.074	-.029	-.023	
			0	8.00	.4503	.328	.126	.202	-.037	.005	-.001	.001	*
			3	7.93	.4495	.366	.154	.212	-.028	.089	.036	.007	
			6	7.92	.4533	.410	.177	.233	-.027	.160	.060	.022	
			9	7.96	.4743	.470	.199	.271	-.035	.226	.090	.036	
			12	8.02	.4964	.542	.232	.311	-.039	.277	.115	.051	
			16	8.05	.5230	.641	.287	.354	-.033	.376	.137	.080	
			20	8.05	.5302	.754	.357	.397	-.020	.495	.145	.106	
			30	8.25	.5329	.973	.509	.464	.022	.742	.176	.187	
			40	8.44	.5523	.957	.509	.447	.031	.913	.189	.240	

LOCKHEED-GEORGIA COMPANY LOW SPEED WIND TUNNEL

1978 EHV DATA BASE — REDUCTION METHOD: HACKETT-WILSDEN

REPORT LSWT 291
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RUN	CONFIGURATION DESCRIPTION		WHEELBASE / AREA	PSI (DEG)	QQ (PSF)	CD	CL	CLF	CLR	CM	CY	CN	CR	
11	1978 PACER SEDAN	RADIATOR BLOCKED, WINDOWS OPEN , FLUSH	8.33	-40	8.36	.7221	.952	.586	.366	.110	-.831	-.135	-.246	
			23.92	-30	8.32	.7418	.791	.486	.305	.090	-.591	-.131	-.180	
				-20	8.12	.6740	.629	.337	.292	.022	-.396	-.102	-.111	
				-16	8.13	.6149	.553	.273	.279	-.002	-.334	-.088	-.089	
				-12	8.00	.5499	.489	.228	.261	-.016	-.269	-.069	-.073	
				-9	7.97	.5146	.441	.196	.245	-.024	-.215	-.052	-.053	
				-6	7.96	.4904	.406	.181	.225	-.021	-.141	-.038	-.036	
				-3	7.94	.4644	.357	.162	.195	-.016	-.075	-.018	-.022	
				0	7.94	.4505	.302	.128	.174	-.023	.012	.000	.002	*
				5	8.00	.4640	.364	.167	.197	-.015	.123	.040	.017	
				9	8.01	.4952	.411	.187	.224	[illegible]	.215	.064	.040	
				12	8.02	.5326	.466	.216	.250	[illegible]	.276	.079	.061	
				16	8.10	.5979	.511	.254	.256	-.001	.345	.096	.082	
				20	8.19	.6505	.546	.304	.242	.030	.422	.106	.101	
				30	8.29	.7139	.693	.441	.252	.094	.626	.128	.170	
				40	8.38	.6981	.950	.564	.386	.089	.820	.141	.242	
12	KAYLOR	RADIATOR N.A. , WINDOWS N.A. , FLUSH	7.71	-20	7.95	.6400	.298	.278	.019	.129	-.548	-.112	-.037	
			14.63	-16	7.87	.6301	.376	.286	.090	.098	-.451	-.092	-.040	
				-12	7.93	.6093	.362	.265	.096	.084	-.315	-.073	-.020	
				-9	7.82	.5975	.303	.213	.090	.061	-.245	-.055	-.029	
				-6	7.82	.5866	.302	.192	.110	.040	-.153	-.040	-.007	
				-3	7.87	.5860	.287	.163	.124	.019	-.077	-.024	-.010	
				0	7.89	.5830	.226	.128	.098	.014	.014	-.007	-.006	*
				3	7.90	.5892	.277	.162	.115	.023	.110	.013	.010	
				6	7.90	.5996	.275	.177	.098	.039	.199	.028	.020	
				9	7.86	.6138	.286	.197	.089	.054	.275	.042	.007	
				12	7.89	.6198	.311	.221	.090	.065	.406	.052	.039	
				16	7.96	.6335	.344	.257	.087	.084	.527	.071	.037	
				20	7.96	.6329	.403	.286	.117	.084	.652	.089	.056	

LOCKHEED-GEORGIA COMPANY LOW SPEED WIND TUNNEL

1978 EHV DATA BASE   REDUCTION METHOD: HACKETT-WILSDEN

REPORT LSWT 291
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RUN	CONFIGURATION DESCRIPTION	WHEELBASE / AREA	PSI (DEG)	QO (PSF)	CD	CL	CLF	CLR	CM	CY	CN	CR
13	GE REFERENCE RADIATOR N.A. , WINDOWS CLOSED, FLUSH	7.67	-40	8.30	.2695	.539	.394	.145	.125	-1.46	-.153	-.275
		19.93	-30	8.14	.3327	.500	.329	.171	.078	-1.24	-.149	-.240
			-20	7.94	.3838	.472	.267	.205	.030	-.852	-.131	-.160
			-16	7.90	.3828	.376	.207	.169	.019	-.703	-.116	-.127
			-12	7.88	.3934	.341	.157	.184	-.013	-.530	-.100	-.096
			-9	7.90	.3849	.284	.109	.175	-.032	-.389	-.080	-.069
			-6	7.92	.3645	.227	.074	.153	-.039	-.272	-.049	-.050
			-3	7.93	.3516	.199	.053	.146	-.045	-.143	-.023	-.034
			0	7.89	.3374	.138	.026	.111	-.042	.006	-.002	-.007 *
			3	7.87	.3444	.195	.065	.130	-.032	.148	.020	.009
			6	7.91	.3541	.195	.070	.125	-.027	.284	.045	.037
			9	7.91	.3733	.249	.106	.142	-.017	.407	.072	.056
			12	7.90	.3791	.284	.139	.145	-.003	.554	.090	.084
			16	7.96	.3823	.387	.205	.182	.011	.736	.107	.122
			20	8.02	.3767	.483	.261	.222	.019	.883	.123	.151
			30	8.16	.3265	.518	.313	.206	.053	1.276	.142	.238
			40	8.42	.2418	.502	.339	.163	.088	1.550	.136	.308
14	GE REFERENCE RADIATOR N.A. , WINDOWS OPEN , FLUSH	7.67	-40	8.46	.3322	.518	.415	.103	.156	-1.40	-.133	-.265
		19.93	-30	8.16	.4095	.451	.333	.119	.107	-1.16	-.128	-.222
			-20	7.98	.4388	.424	.259	.165	.047	-.848	-.106	-.163
			-16	7.97	.4298	.352	.206	.146	.029	-.729	-.089	-.139
			-12	7.89	.4165	.301	.145	.156	-.005	-.554	-.077	-.102
			-9	7.87	.3975	.266	.106	.159	-.026	-.402	-.064	-.072
			-6	7.89	.3763	.242	.077	.165	-.043	-.282	-.041	-.058
			-3	7.88	.3594	.239	.072	.166	-.046	-.143	-.020	-.033
			0	7.91	.3423	.205	.055	.150	-.047	.007	-.001	.000 *
			3	7.84	.3527	.202	.056	.145	-.044	.153	.014	.019
			6	7.86	.3672	.214	.070	.143	-.036	.291	.035	.046
			9	7.92	.3861	.230	.089	.140	-.025	.413	.055	.063
			12	7.92	.4034	.277	.137	.140	-.001	.566	.071	.091
			16	8.00	.4189	.336	.186	.150	.018	.744	.083	.122
			20	8.05	.4211	.405	.235	.170	.032	.867	.102	.153
			30	8.26	.3858	.470	.304	.166	.068	1.200	.121	.233
			40	8.45	.3013	.485	.365	.120	.123	1.472	.116	.292

LOCKHEED-GEORGIA COMPANY LOW SPEED WIND TUNNEL

1978 EHV DATA BASE REDUCTION METHOD: HACKETT-WILSDEN

REPORT LSWT 291
MODEL JPL
DATE 8-14-78

RUN	CONFIGURATION DESCRIPTION	WHEELBASE / AREA	PSI (DEG)	QO (PSF)	CD	CL	CLF	CLR	CM	CY	CN	CR	
15	1978 DELTA 88 SEDAN RADIATOR OPEN , WINDOWS CLOSED, FLUSH	9.67	-40	8.82	.8248	1.399	.750	.650	.049	-1.57	-.132	-.483	
		22.36	-30	8.51	.8331	1.053	.573	.480	.046	-1.15	-.188	-.367	
			-20	8.14	.7409	.876	.465	.411	.027	-.823	-.202	-.258	
			-16	8.10	.6998	.809	.437	.372	.032	-.685	-.179	-.208	
			-12	8.13	.6561	.691	.393	.298	.047	-.520	-.146	-.156	
			-9	8.05	.6194	.586	.369	.217	.075	-.372	-.117	-.116	
			-6	8.00	.5844	.507	.349	.158	.095	-.242	-.082	-.076	
			-3	8.00	.5692	.467	.333	.135	.098	-.082	-.050	-.037	
			0	8.03	.5579	.447	.307	.140	.083	.031	-.011	.010	*
			3	8.03	.5585	.464	.334	.130	.102	.133	.040	.024	
			6	8.04	.5757	.521	.358	.164	.097	.253	.087	.060	
			9	8.04	.6048	.607	.389	.218	.085	.393	.116	.100	
			12	8.07	.6414	.702	.431	.271	.079	.512	.141	.140	
			16	8.17	.6845	.803	.451	.352	.049	.690	.173	.194	
			20	8.31	.7202	.894	.489	.405	.041	.815	.197	.242	
			30	8.52	.8142	1.124	.631	.493	.069	1.149	.178	.370	
			40	8.90	.7826	1.519	.835	.684	.075	1.612	.125	.512	
16	78 HONDA CIVIC SEDAN RADIATOR BLOCKED, WINDOWS CLOSED,1" PAD	7.22	-40	8.59	.5833	.621	.556	.064	.239	-1.59	-.139	-.419	
		17.55	-30	8.34	.6490	.605	.486	.119	.176	-1.24	-.148	-.332	
			-20	8.05	.6190	.520	.346	.174	.078	-.899	-.133	-.257	
			-16	7.98	.6212	.480	.294	.186	.047	-.721	-.113	-.206	
			-12	7.89	.6045	.418	.227	.191	.011	-.547	-.090	-.160	
			-9	7.90	.5702	.325	.172	.152	.003	-.408	-.066	-.120	
			-6	7.88	.5450	.318	.147	.171	-.018	-.291	-.042	-.096	
			-3	7.90	.5316	.300	.124	.176	-.031	-.162	-.016	-.058	
			0	7.89	.5027	.249	.105	.144	-.025	-.009	.002	-.006	*
			3	7.83	.5348	.306	.126	.180	-.033	.144	.023	.006	
			6	7.92	.5510	.324	.148	.176	-.020	.276	.045	.052	
			9	7.91	.5751	.343	.177	.166	-.001	.405	.069	.086	
			12	8.04	.6026	.406	.220	.186	.010	.538	.090	.128	
			16	7.98	.6127	.505	.294	.212	.034	.719	.112	.180	
			20	8.09	.6107	.543	.340	.203	.061	.879	.131	.232	
			30	8.34	.6277	.468	.401	.067	.160	1.266	.139	.327	
			40	8.55	.5914	.503	.454	.048	.196	1.501	.127	.402	

LOCKHEED-GEORGIA COMPANY LOW SPEED WIND TUNNEL

1978 EHV DATA BASE REDUCTION METHOD: HACKETT-WILSDEN

REPORT LSWT 291
MODEL JPL
DATE 8-14-78

RUN	CONFIGURATION DESCRIPTION	WHEELBASE AREA	PSI (DEG)	QO (PSF)	CD	CL	CLF	CLR	CM	CY	CN	CR	
17	78 HONDA CIVIC SEDAN RADIATOR BLOCKED, WINDOWS OPEN ,1" PAD	7.22	-40	8.42	.7546	.662	.641	.020	.302	-1.42	-.077	-.390	
		17.55	-30	8.20	.8312	.520	.501	.018	.232	-1.05	-.082	-.288	
			-20	8.12	.7640	.449	.351	.098	.117	-.778	-.057	-.225	
			-16	8.16	.7055	.423	.285	.138	.065	-.663	-.040	-.197	
			-12	8.08	.6453	.364	.218	.147	.028	-.517	-.036	-.156	
			-9	7.99	.5978	.331	.174	.156	.002	-.387	-.032	-.117	
			-6	7.94	.5412	.284	.138	.146	-.009	-.263	-.027	-.089	
			-3	7.82	.4942	.215	.109	.106	-.004	-.128	-.017	-.049	
			0	7.91	.4946	.237	.102	.135	-.022	.008	-.003	-.002	*
			3	7.92	.5063	.262	.123	.139	-.013	.135	.015	.013	
			6	7.92	.5398	.286	.135	.151	-.014	.252	.028	.044	
			9	7.86	.5913	.314	.161	.152	-.002	.396	.033	.094	
			12	8.14	.6491	.368	.205	.163	.013	.516	.038	.125	
			16	8.09	.7198	.435	.279	.156	.052	.673	.041	.170	
			20	8.18	.7907	.472	.351	.122	.105	.800	.051	.215	
			30	8.30	.8104	.465	.462	.003	.220	1.102	.075	.289	
			40	8.56	.7295	.528	.554	-.026	.282	1.420	.065	.375	
18	78 HONDA CIVIC WAGON RADIATOR BLOCKED, WINDOWS CLOSED,1" PAD	7.48	-40	8.57	.5763	.471	.449	.021	.208	-1.70	-.059	-.452	
		18.14	-30	8.37	.6588	.450	.379	.070	.147	-1.38	-.083	-.363	
			-20	8.14	.6457	.448	.313	.135	.081	-1.02	-.093	-.278	
			-16	8.10	.6405	.472	.273	.199	.030	-.830	-.087	-.234	
			-12	7.93	.6290	.379	.216	.163	.019	-.605	-.072	-.174	
			-9	7.93	.6024	.288	.160	.128	.009	-.456	-.059	-.133	
			-6	7.93	.5616	.203	.121	.081	.013	-.314	-.041	-.101	
			-3	7.96	.5271	.164	.101	.063	.012	-.156	-.024	-.054	
			0	7.93	.5137	.139	.070	.069	-.005	-.000	-.015	-.002	*
			3	7.92	.5236	.152	.090	.062	.008	.140	.008	.011	
			6	7.89	.5438	.175	.104	.071	.010	.307	.020	.063	
			9	7.92	.5678	.199	.126	.072	.020	.455	.039	.092	
			12	7.93	.5882	.258	.179	.078	.043	.596	.054	.127	
			16	8.05	.5920	.327	.228	.098	.057	.820	.074	.195	
			20	8.08	.5905	.424	.282	.142	.063	1,015	.086	.254	
			30	8.27	.5857	.367	.352	.015	.162	1.416	.072	.352	
			40	8.66	.5413	.387	.398	-.010	.198	1.678	.049	.431	

LOCKHEED-GEORGIA COMPANY LOW SPEED WIND TUNNEL

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REPORT LSWT 291
MODEL JPL
DATE 8-14-78

RUN	CONFIGURATION DESCRIPTION	WHEELBASE AREA	PSI (DEG)	QD (PSF)	CD	CL	CLF	CLR	CM	CY	CN	CR	
19	78 HONDA CIVIC WAGON RADIATOR BLOCKED, WINDOWS OPEN ,1" PAD	7.48	-40	8.66	.7095	.546	.553	-.006	.272	-1.62	-.003	-.444	
		18.14	-30	8.38	.7889	.455	.427	.027	.191	-1.29	-.020	-.361	
			-20	8.16	.7424	.359	.292	.066	.105	-.980	-.025	-.279	
			-16	8.08	.7215	.391	.256	.135	.052	-.828	-.024	-.247	
			-12	8.13	.6793	.319	.189	.130	.021	-.628	-.023	-.189	
			-9	7.94	.6306	.262	.151	.111	.012	-.470	-.022	-.142	
			-6	7.95	.5761	.192	.112	.079	.009	-.324	-.019	-.108	
			-3	7.86	.5259	.138	.081	.056	.006	-.161	-.016	-.061	
			0	7.95	.4921	.088	.061	.027	.011	-.009	-.014	-.010	*
			3	7.93	.5131	.101	.071	.029	.015	.142	.000	.015	
			6	8.04	.5477	.144	.095	.049	.017	.299	.007	.052	
			9	7.99	.5886	.173	.119	.054	.025	.452	.011	.091	
			12	8.10	.6422	.214	.165	.048	.050	.601	.009	.126	
			16	8.10	.6846	.266	.207	.058	.066	.810	.014	.189	
			20	8.24	.7149	.325	.270	.055	.099	.972	.018	.244	
			30	8.35	.7351	.411	.400	.011	.186	1.310	.012	.344	
			40	8.73	.6687	.473	.513	-.039	.269	1.605	-.005	.427	
20	HYBRID ELECTRIC VAN RADIATOR N.A. , WINDOWS CLOSED, FLUSH	7.83	-15	8.53	.5677	.190	.329	-.138	.234	-.971	-.294	-.397	
		35.34	-12	8.43	.5431	.159	.293	-.133	.213	-.790	-.239	-.320	
			-9	8.39	.5451	.130	.260	-.131	.196	-.604	-.200	-.250	
			-6	8.36	.5290	.091	.228	-.136	.182	-.396	-.132	-.165	
			-3	8.37	.5077	.061	.211	-.150	.180	-.173	-.059	-.075	
			0	8.34	.4965	.047	.206	-.159	.183	.026	.019	.008	*
			3	8.37	.4969	.053	.221	-.167	.194	.203	.088	.078	
			6	8.19	.4941	.082	.242	-.159	.200	.408	.141	.159	
			9	8.43	.5147	.123	.271	-.149	.210	.610	.201	.238	
			12	8.47	.5356	.193	.333	-.140	.236	.797	.249	.315	
			15	8.49	.5578	.243	.390	-.147	.268	.973	.289	.391	
21	HYBRID ELECTRIC VAN RADIATOR N.A. , WINDOWS OPEN , FLUSH	7.83	-15	8.47	.5712	.182	.327	-.145	.236	-.893	-.240	-.361	
		35.34	-12	8.45	.5589	.162	.293	-.132	.213	-.747	-.198	-.301	
			-9	8.29	.5340	.137	.262	-.125	.193	-.562	-.156	-.231	
			-6	8.50	.5296	.088	.230	-.141	.186	-.371	-.104	-.155	
			-3	8.43	.5045	.049	.200	-.150	.175	-.177	-.052	-.075	
			0	8.37	.4973	.032	.196	-.164	.180	.018	.007	.006	*
			3	8.29	.4833	.046	.206	-.160	.183	.193	.066	.073	
			6	8.35	.5046	.067	.235	-.168	.201	.383	.113	.150	
			9	8.32	.5217	.126	.275	-.150	.213	.572	.165	.224	
			12	8.54	.5491	.157	.311	-.154	.232	.762	.212	.299	
			15	8.66	.5669	.209	.374	-.166	.270	.915	.239	.367	

LOCKHEED-GEORGIA COMPANY LOW SPEED WIND TUNNEL

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REPORT LSWT 291
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RUN	CONFIGURATION DESCRIPTION	WHEELBASE AREA	PSI (DEG)	QD (PSF)	CD	CL	CLF	CLR	CM	CY	CN	CR	
22	1978 FORD FIESTA RADIATOR BLOCKED, WINDOWS CLOSED,.5"PAD	7.50	-40	8.92	.5461	.425	.398	.027	.183	-1.58	-.071	-.441	
		18.80	-30	8.77	.5754	.370	.330	.039	.143	-1.34	-.122	-.367	
			-20	8.42	.5629	.389	.295	.094	.098	-1.02	-.103	-.280	
			-16	8.37	.5542	.337	.251	.085	.080	-.823	-.098	-.227	
			-12	8.42	.5399	.253	.199	.054	.070	-.625	-.079	-.179	
			-9	8.37	.5074	.146	.156	-.010	.081	-.474	-.062	-.139	
			-6	8.29	.4802	.045	.107	-.061	.082	-.312	-.043	-.097	
			-3	8.34	.4728	-.008	.090	-.099	.093	-.159	-.023	-.062	
			0	8.30	.4677	-.055	.068	-.123	.093	.007	-.004	.000	*
			3	8.30	.4622	-.027	.081	-.108	.092	.156	.019	.017	
			6	8.28	.4712	.038	.108	-.068	.086	.311	.040	.062	
			9	8.39	.4858	.129	.142	-.012	.075	.463	.056	.102	
			12	8.31	.5434	.306	.201	.105	.045	.599	.075	.144	
			16	8.49	.5457	.368	.239	.129	.052	.796	.092	.199	
			20	8.46	.5393	.419	.281	.138	.069	.994	.107	.261	
			30	8.74	.5187	.424	.336	.087	.122	1.366	.114	.366	
			40	9.00	.5014	.428	.371	.056	.155	1.557	.075	.427	
23	1978 FORD FIESTA RADIATOR BLOCKED, WINDOWS OPEN ,.5"PAD	7.50	-40	8.92	.6590	.427	.457	-.029	.240	-1.45	-.035	-.413	
		18.80	-30	8.74	.6809	.318	.340	-.022	.178	-1.18	-.079	-.343	
			-20	8.52	.6948	.332	.289	.042	.121	-.865	-.067	-.247	
			-16	8.49	.6691	.323	.254	.068	.089	-.732	-.054	-.213	
			-12	8.50	.6277	.237	.196	.041	.074	-.578	-.032	-.167	
			-9	8.30	.5982	.249	.175	.074	.047	-.445	-.024	-.142	
			-6	8.41	.5430	.139	.128	.010	.056	-.316	-.011	-.114	
			-3	8.30	.5076	-.024	.077	-.102	.087	-.167	-.003	-.068	
			0	8.33	.4967	-.054	.062	-.117	.087	.001	-.006	-.005	*
			3	8.33	.4936	-.022	.080	-.104	.090	.148	.003	.016	
			6	8.23	.5322	.157	.131	.026	.050	.281	.010	.051	
			9	8.36	.5674	.227	.164	.062	.048	.436	.016	.099	
			12	8.46	.6128	.268	.194	.074	.056	.559	.019	.131	
			16	8.47	.6564	.314	.241	.073	.081	.709	.034	.168	
			20	8.49	.6761	.340	.281	.058	.109	.859	.045	.220	
			30	8.78	.6479	.373	.363	.010	.174	1.196	.070	.317	
			40	9.04	.6166	.435	.458	-.022	.238	1.418	.027	.394	

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RUN	CONFIGURATION DESCRIPTION	WHEELBASE AREA	PSI (DEG)	QO (PSF)	CD	CL	CLF	CLR	CM	CY	CN	CR	
25	1967 CORVETTE RADIATOR BLOCKED, WINDOWS CLOSED, FLUSH	8.17	-40	8.28	.5074	1.674	1.054	.620	.217	-1.23	-.193	-.242	
		20.72	-30	8.05	.5461	1.521	.941	.580	.181	-.861	-.220	-.185	
			-20	7.89	.5392	1.122	.669	.453	.108	-.552	-.177	-.115	
			-16	8.02	.5237	.932	.570	.362	.104	-.456	-.140	-.095	
			-12	8.01	.5153	.760	.483	.277	.103	-.370	-.102	-.078	
			-9	7.86	.5122	.636	.419	.217	.101	-.281	-.075	-.055	
			-6	7.89	.5070	.565	.377	.188	.094	-.184	-.052	-.030	
			-3	7.94	.4975	.499	.354	.145	.104	-.101	-.024	-.020	
			0	7.94	.4902	.451	.320	.130	.095	-.002	.002	.000	*
			3	7.97	.4888	.464	.336	.128	.104	.106	.026	.026	
			6	7.97	.4936	.523	.362	.160	.101	.189	.054	.039	
			9	7.99	.5012	.613	.406	.207	.099	.282	.077	.061	
			12	8.00	.4865	.725	.460	.265	.097	.373	.103	.089	
			16	7.94	.5069	.923	.562	.361	.101	.476	.137	.112	
			20	8.01	.5189	1.162	.660	.502	.079	.561	.178	.131	
			30	8.10	.5261	1.565	.898	.667	.115	.816	.228	.207	
			40	8.33	.5151	1.783	1.024	.759	.133	1.048	.215	.269	
26	1967 CORVETTE RADIATOR BLOCKED, WINDOWS OPEN , FLUSH	8.17	-40	8.47	.5743	1.502	.981	.521	.230	-1.13	-.174	-.250	
		20.72	-30	8.23	.6243	1.364	.893	.471	.211	-.791	-.194	-.186	
			-20	8.14	.5929	1.052	.645	.407	.119	-.503	-.161	-.119	
			-16	8.09	.5785	.866	.541	.325	.108	-.417	-.130	-.102	
			-12	8.03	.5559	.721	.470	.251	.109	-.320	-.101	-.078	
			-9	8.00	.5363	.617	.414	.202	.106	-.237	-.081	-.056	
			-6	7.95	.5143	.522	.370	.152	.109	-.171	-.048	-.039	
			-3	7.98	.4986	.459	.348	.111	.119	-.092	-.025	-.028	
			0	7.97	.4877	.416	.319	.097	.111	-.006	.003	-.003	*
			3	8.02	.4921	.431	.333	.098	.117	.101	.025	.012	
			6	7.98	.5030	.489	.360	.129	.116	.180	.049	.026	
			9	7.98	.5157	.586	.405	.181	.112	.261	.074	.045	
			12	8.01	.5296	.713	.460	.254	.103	.314	.103	.066	
			16	8.04	.5546	.902	.549	.353	.097	.405	.132	.087	
			20	8.08	.5732	1.099	.638	.461	.088	.498	.168	.119	
			30	8.15	.5956	1.448	.869	.579	.144	.721	.220	.191	
			40	8.29	.5717	1.544	.942	.602	.170	.943	.205	.260	
27	1967 CORVETTE RADIATOR BLOCKED, WINDOWS CLOSED, FLUSH HEADLIGHTS	8.17 / 20.72	0	7.92	.5042	.445	.349	.096	.126	.004	.001	.004	*
28	1967 CORVETTE RADIATOR OPEN , WINDOWS CLOSED, FLUSH	8.17 / 20.72	0	7.92	.5238	.510	.402	.108	.147	-.001	.003	.006	*

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RUN	CONFIGURATION DESCRIPTION	WHEELBASE AREA	PSI (DEG)	QD (PSF)	CD	CL	CLF	CLR	CM	CY	CN	CR
29	TOWN CAR RADIATOR N.A. , WINDOWS CLOSED,1" PAD	6.67	-40	8.36	.3686	.408	.286	.121	.077	-1.51	-.169	-.450
		18.88	-30	8.21	.4165	.672	.414	.259	.072	-1.27	-.209	-.356
			-20	7.99	.4294	.611	.335	.276	.024	-.785	-.188	-.222
			-16	7.91	.4284	.581	.293	.289	-.003	-.563	-.181	-.158
			-12	7.88	.4193	.498	.223	.275	-.030	-.375	-.157	-.115
			-9	7.89	.4036	.451	.190	.261	-.040	-.296	-.127	-.100
			-6	7.81	.4014	.426	.163	.264	-.055	-.192	-.088	-.085
			-3	7.86	.3857	.410	.142	.268	-.067	-.094	-.045	-.045
			0	7.88	.3672	.390	.110	.280	-.089	.012	-.005	-.002 *
			3	7.95	.3871	.394	.137	.257	-.064	.112	.042	.004
			6	7.89	.4081	.442	.167	.275	-.059	.209	.087	.032
			9	7.92	.4023	.477	.190	.288	-.053	.294	.122	.050
			12	7.91	.4176	.528	.230	.298	-.039	.395	.151	.079
			16	7.93	.4209	.513	.282	.231	.020	.653	.160	.146
			20	7.99	.4270	.598	.347	.252	.042	.813	.182	.197
			30	8.22	.4172	.672	.433	.239	.091	1.275	.208	.368
			40	8.49	.3292	.515	.399	.115	.138	1.661	.174	.483
30	TOWN CAR RADIATOR N.A. , WINDOWS OPEN ,1" PAD	6.67	-40	8.34	.5738	.400	.377	.022	.170	-1.35	-.117	-.436
		18.88	-30	8.20	.6210	.476	.411	.065	.165	-1.08	-.130	-.332
			-20	7.98	.5672	.489	.327	.161	.076	-.708	-.121	-.226
			-16	7.90	.5437	.461	.285	.176	.047	-.515	-.121	-.159
			-12	8.01	.4954	.414	.225	.189	.011	-.357	-.111	-.119
			-9	7.85	.4586	.386	.187	.199	-.011	-.265	-.091	-.096
			-6	7.86	.4369	.374	.157	.217	-.035	-.170	-.063	-.070
			-3	7.87	.4093	.372	.134	.238	-.056	-.091	-.031	-.054
			0	7.89	.3861	.356	.110	.246	-.072	.018	-.003	.000 *
			3	7.86	.4129	.355	.128	.227	-.054	.109	.027	.004
			6	7.83	.4398	.379	.157	.222	-.037	.206	.061	.043
			9	7.85	.4709	.414	.194	.220	-.019	.288	.082	.065
			12	7.96	.5186	.452	.238	.214	.005	.377	.102	.091
			16	7.95	.5531	.501	.297	.204	.039	.514	.121	.136
			20	8.02	.5775	.543	.364	.178	.085	.719	.114	.201
			30	8.34	.6293	.459	.432	.026	.195	1.096	.111	.332
			40	8.57	.5258	.475	.469	.006	.224	1.441	.114	.456

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RUN	CONFIGURATION DESCRIPTION	WHEELBASE AREA	PSI (DEG)	QO (PSF)	CD	CL	CLF	CLR	CM	CY	CN	CP
31	CITI CAR RADIATOR N.A. , WINDOWS CLOSED,1" PAD	5.46	-40	8.70	.5972	.095	.315	-.220	.258	-1.33	-.038	-.457
		18.30	-30	8.42	.6490	.055	.264	-.209	.226	-1.29	-.068	-.457
			-20	8.09	.6615	.087	.261	-.174	.207	-1.09	-.093	-.399
			-16	8.02	.6334	.087	.253	-.165	.199	-.977	-.088	-.361
			-12	7.98	.5959	.041	.191	-.150	.161	-.777	-.072	-.303
			-9	7.97	.5723	.039	.176	-.136	.147	-.603	-.059	-.241
			-6	7.94	.5519	.019	.154	-.134	.136	-.410	-.042	-.167
			-3	7.91	.5478	-.002	.143	-.145	.135	-.210	-.019	-.091
			0	7.96	.5413	-.050	.110	-.161	.127	.000	-.001	-.002
			3	7.95	.5407	-.046	.112	-.159	.127	.197	.024	.054
			6	7.93	.5404	-.015	.133	-.149	.133	.388	.045	.121
			9	8.01	.5572	.015	.160	-.145	.144	.573	.063	.188
			12	8.01	.5645	.047	.193	-.145	.160	.762	.076	.266
			16	8.08	.5857	.101	.243	-.142	.183	.977	.091	.339
			20	8.07	.6150	.126	.270	-.145	.198	1.115	.102	.377
			30	8.46	.6389	.111	.259	-.147	.193	1.274	.067	.436
			40	8.65	.5831	.123	.292	-.170	.222	1.285	.033	.424
32	CITI CAR RADIATOR N.A. , WINDOWS OPEN ,1" PAD	5.46	-40	8.69	.6591	.131	.382	-.251	.306	-1.26	-.017	-.437
		18.30	-30	8.39	.7439	.034	.330	-.296	.301	-1.09	-.015	-.374
			-20	8.17	.7630	-.011	.270	-.282	.264	-.921	-.022	-.318
			-16	8.10	.7144	-.015	.226	-.242	.223	-.839	-.024	-.302
			-12	8.01	.6640	-.015	.187	-.203	.185	-.697	-.031	-.263
			-9	8.04	.6199	-.006	.162	-.169	.156	-.568	-.025	-.222
			-6	7.96	.5814	-.002	.143	-.145	.135	-.412	-.016	-.177
			-3	7.97	.5600	-.001	.136	-.137	.128	-.227	-.006	-.103
			0	7.95	.5570	-.031	.119	-.151	.126	-.006	.000	-.011
			3	7.96	.5561	-.034	.114	-.148	.123	.192	.009	.044
			6	7.93	.5687	-.031	.126	-.157	.133	.391	.019	.135
			9	8.04	.6026	-.016	.159	-.176	.158	.544	.028	.180
			12	8.04	.6438	-.013	.191	-.205	.188	.675	.037	.233
			16	8.22	.6985	-.016	.227	-.243	.225	.819	.035	.278
			20	8.19	.7336	-.012	.271	-.283	.266	.926	.034	.314
			30	8.42	.7187	.059	.315	-.256	.274	1.105	.027	.376
			40	8.76	.6292	.129	.344	-.215	.270	1.256	.021	.428

LOCKHEED-GEORGIA COMPANY LOW SPEED WIND TUNNEL

1978 EHV DATA BASE REDUCTION METHOD: HACKETT-WILSDEN

REPORT LSWT 291
MODEL JPL
DATE 8-14-78

RUN	CONFIGURATION DESCRIPTION	WHEELBASE AREA	PSI (DEG)	QO (PSF)	CD	CL	CLF	CLR	CM	CY	CN	CR	
33	ELCAR RADIATOR N.A. , WINDOWS CLOSED,1" PAD	4.25	-40	8.52	.6431	.084	.394	-.309	.339	-.993	-.032	-.567	
		19.79	-30	8.39	.6861	.041	.366	-.324	.331	-.802	-.028	-.446	
			-20	8.17	.6331	.045	.315	-.269	.279	-.587	-.011	-.328	
			-16	8.14	.6066	.047	.283	-.236	.248	-.508	-.001	-.301	
			-12	7.99	.5532	-.001	.219	-.221	.209	-.420	-.002	-.257	
			-9	8.01	.5357	.000	.208	-.207	.197	-.307	.002	-.194	
			-6	7.98	.5126	-.000	.184	-.185	.174	-.203	.006	-.136	
			-3	7.84	.4921	-.055	.147	-.202	.165	-.096	.011	-.058	
			0	7.94	.4899	.022	.153	-.130	.132	.017	.007	.010	*
			3	7.90	.4747	-.074	.120	-.195	.148	.153	.009	.080	
			6	7.88	.5008	-.023	.167	-.191	.169	.248	.002	.137	
			9	8.01	.5184	-.006	.188	-.195	.181	.360	.005	.203	
			12	8.02	.5423	.025	.227	-.202	.203	.460	.006	.254	
			16	8.11	.5748	.037	.257	-.220	.228	.564	.008	.323	
			20	8.11	.6046	.055	.289	-.234	.249	.670	.008	.390	
			30	8.39	.6645	.054	.347	-.293	.307	.816	.014	.461	
			40	8.58	.6005	.091	.361	-.269	.303	1.013	.020	.561	
34	ELCAR RADIATOR N.A. , WINDOWS OPEN ,1" PAD	4.25	-40	8.52	.6625	.093	.418	-.324	.358	-.977	-.015	-.560	
		19.79	-30	8.36	.7006	.038	.373	-.334	.340	-.786	-.015	-.447	
			-20	8.21	.6491	-.021	.277	-.298	.275	-.559	.001	-.314	
			-16	8.10	.6084	-.016	.234	-.250	.230	-.474	.008	-.280	
			-12	8.11	.5626	-.011	.195	-.207	.190	-.406	.009	-.247	
			-9	8.00	.5377	-.011	.173	-.184	.168	-.307	.009	-.192	
			-6	7.93	.5137	-.027	.144	-.172	.148	-.222	.009	-.146	
			-3	7.98	.4848	-.047	.109	-.157	.124	-.121	.009	-.094	
			0	7.96	.4871	.014	.126	-.112	.110	.003	.002	-.003	*
			3	7.90	.4823	-.065	.099	-.165	.123	.144	-.004	.070	
			6	8.01	.5073	-.047	.127	-.174	.141	.235	-.012	.119	
			9	8.00	.5360	-.029	.161	-.190	.165	.336	-.014	.170	
			12	8.03	.5575	-.003	.189	-.193	.180	.436	-.014	.224	
			16	8.16	.5900	-.001	.228	-.230	.217	.536	-.008	.272	
			20	8.24	.6342	.005	.263	-.257	.247	.619	-.004	.351	
			30	8.44	.7123	.019	.374	-.355	.350	.779	-.003	.407	
			40	8.60	.6504	.096	.408	-.311	.347	.984	.003	.517	

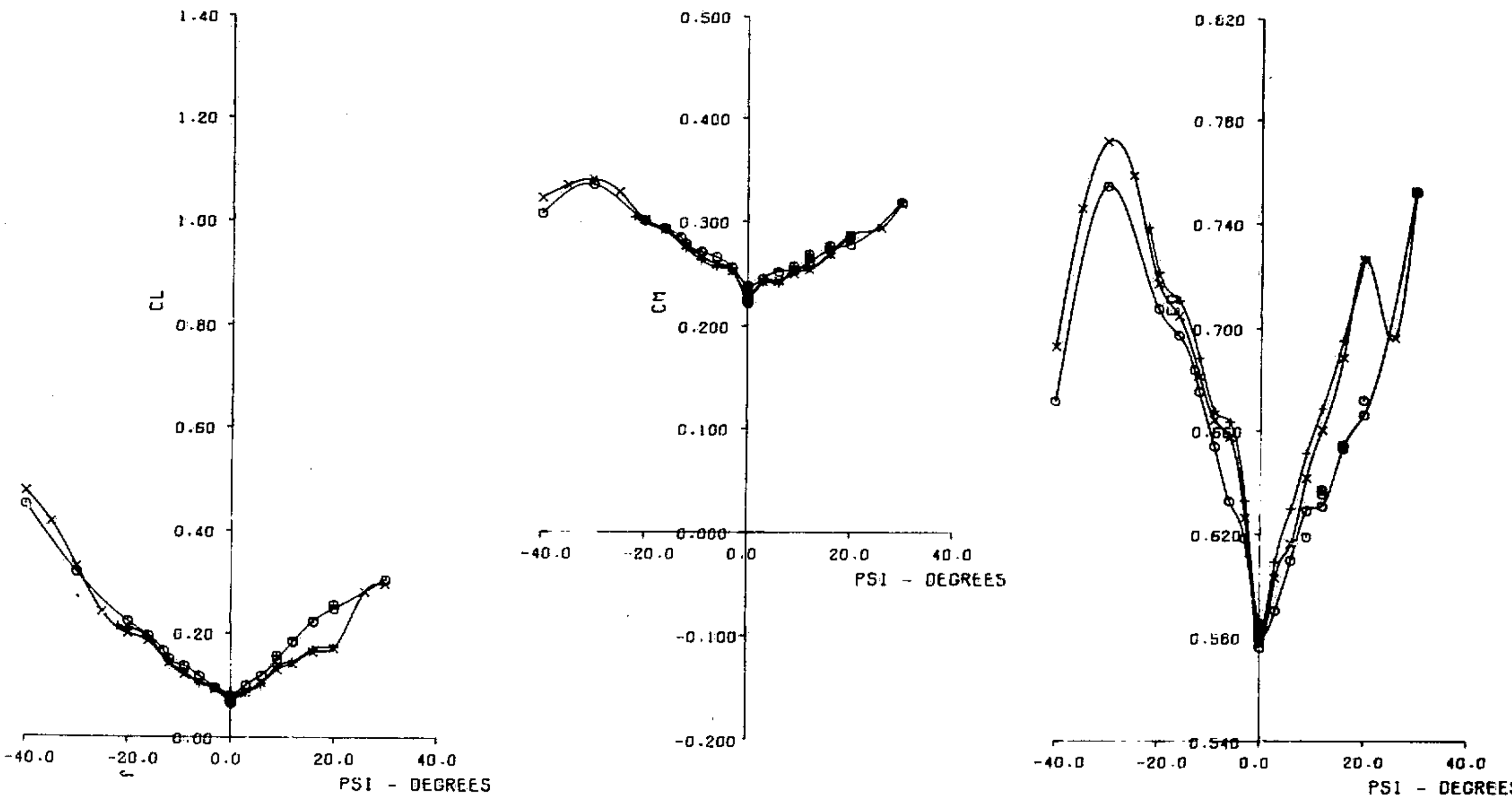
PART II: GRAPHIC FORMAT

SYM	RUN	CONFIGURATION		Q PSF
⊙	1	OTIS VAN	RADIATOR N.A. , WINDOWS CLOSED, FLUSH	8.22
×	2	OTIS VAN	RADIATOR N.A. , WINDOWS OPEN , FLUSH	8.26
+	3	OTIS VAN	RADIATOR N.A. , WINDOWS OPEN , FLUSH	8.3.

OTIS VAN
LIFT, PITCHING MOMENT, AND DRAG
CHARACTERISTICS

PAGE
FIGURE

LSWT 291
DATE 11-07-78

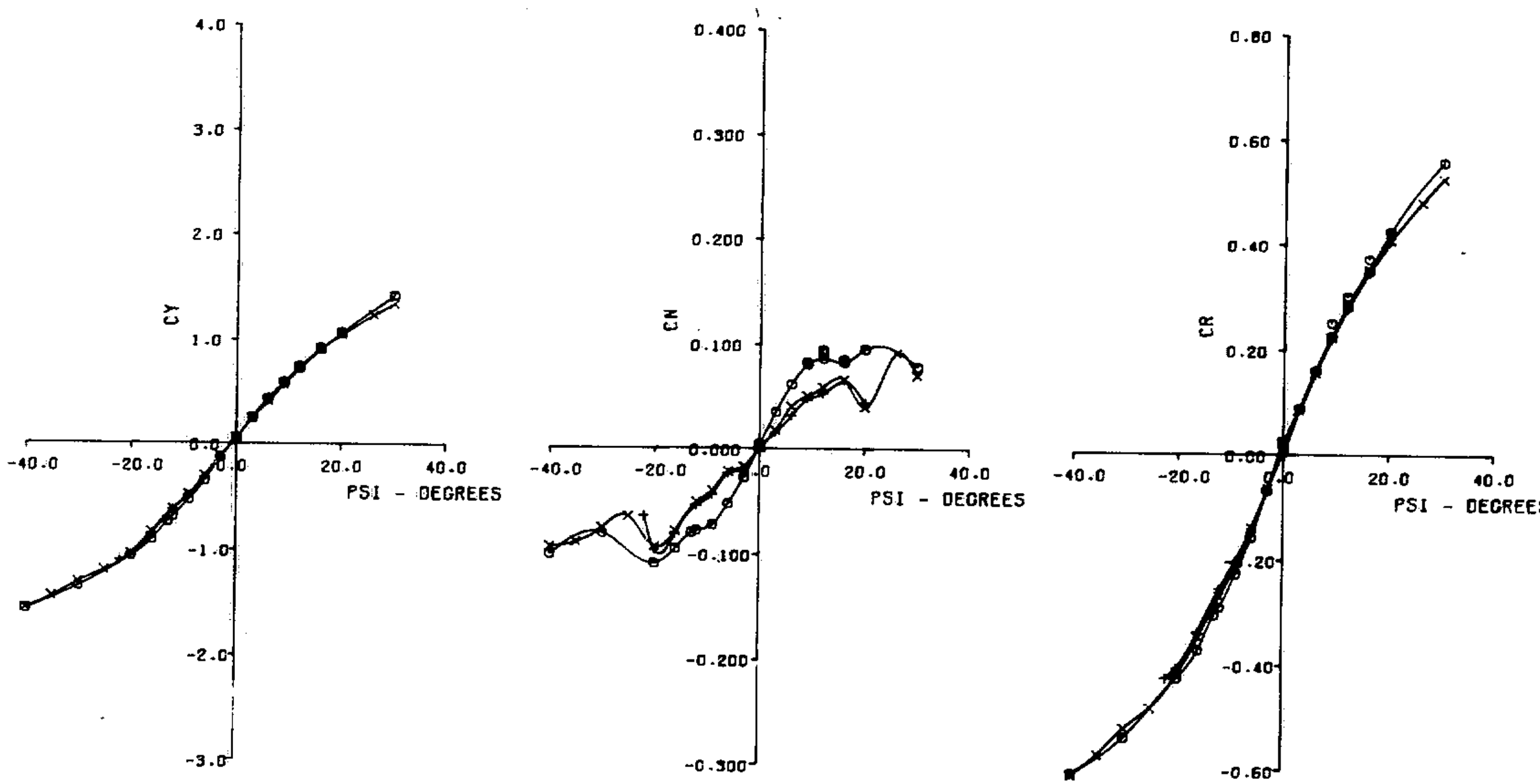


SYM	RUN	CONFIGURATION		Q PSF
o	1	OTIS VAN	RADIATOR N.A. , WINDOWS CLOSED, FLUSH	8.22
x	2	OTIS VAN	RADIATOR N.A. , WINDOWS OPEN , FLUSH	8.26
+	3	OTIS VAN	RADIATOR N.A. , WINDOWS OPEN , FLUSH	8.31

OTIS VAN
SIDEFORCE, YAWING AND ROLLING MOMENT
CHARACTERISTICS

PAGE
FIGURE

LSWT 291
DATE 11-07-78

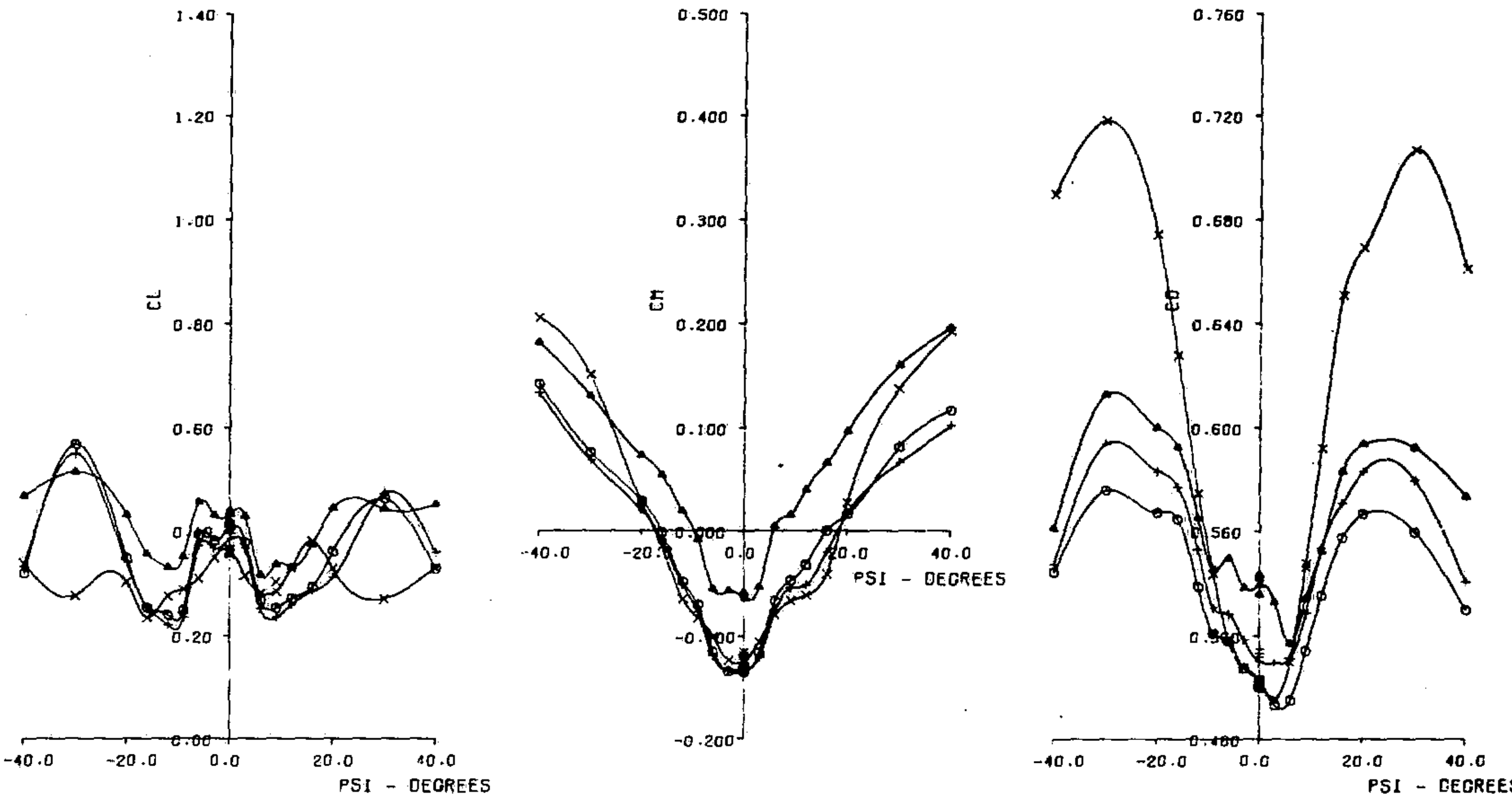


SYM	RUN	CONFIGURATION	Q PSF
○	4	1978 CHEVETTE 4 DR. RADIATOR BLOCKED. WINDOWS CLOSED. FLUSH	7.99
×	5	1978 CHEVETTE 4 DR. RADIATOR BLOCKED. WINDOWS OPEN . FLUSH	7.85
+	6	1978 CHEVETTE 4 DR. RADIATOR BLOCKED. WINDOWS CLOSED.1* PRO	7.92
▲	7	1978 CHEVETTE 4 DR. RADIATOR OPEN . WINDOWS CLOSED. FLUSH	7.97

1978 CHEVETTE 4-DOOR
LIFT, PITCHING MOMENT, AND DRAG CHARACTERISTICS

PAGE
FIGURE

LSWT 291
DATE . 11-07-78

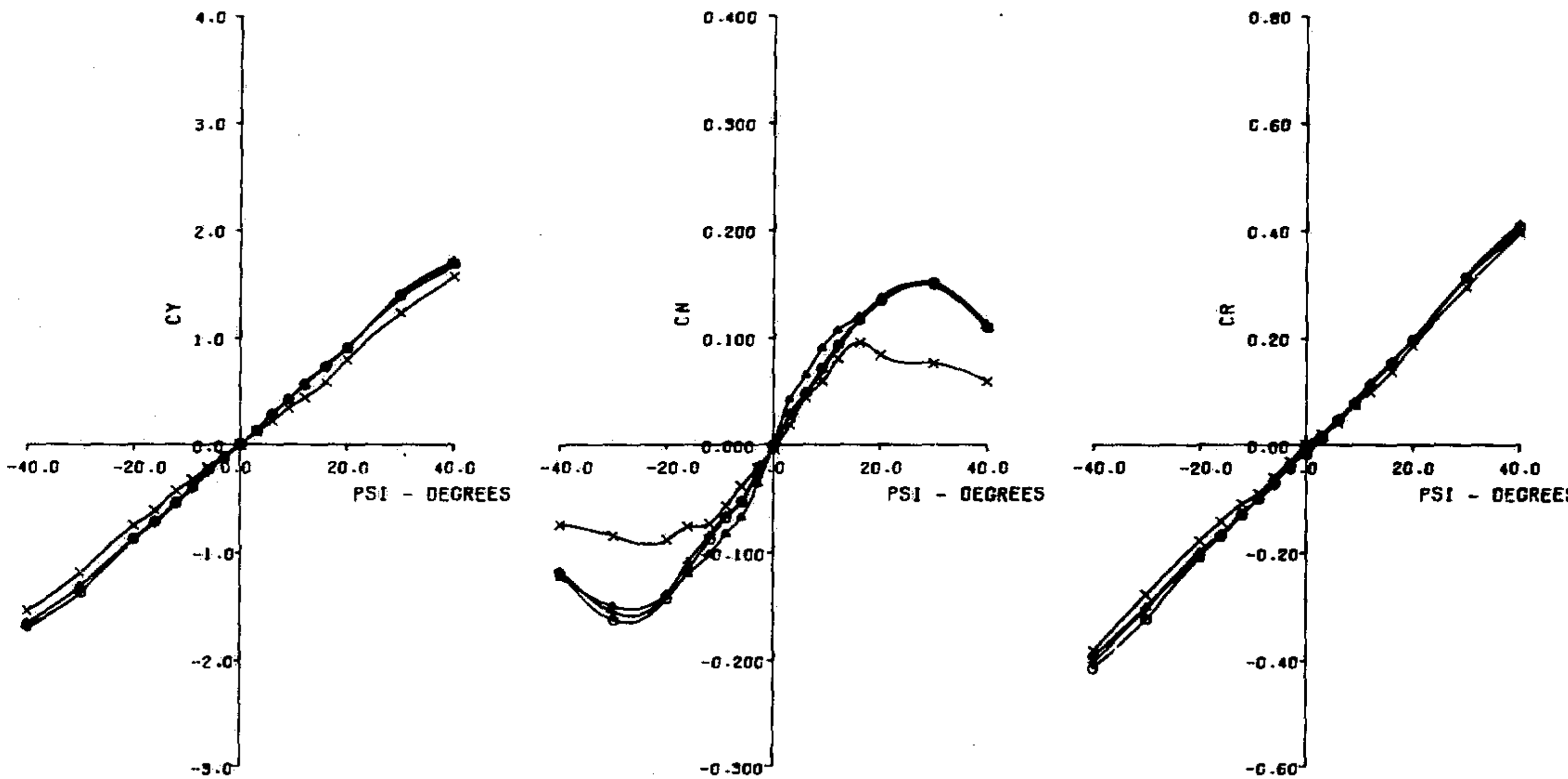


SYM	RUN	CONFIGURATION	Q PSF
○	4	1978 CHEVETTE 4 DR. RADIATOR BLOCKED. WINDOWS CLOSED. FLUSH	7.99
×	5	1978 CHEVETTE 4 DR. RADIATOR BLOCKED. WINDOWS OPEN . FLUSH	7.85
+	6	1978 CHEVETTE 4 DR. RADIATOR BLOCKED. WINDOWS CLOSED.10 RAD	7.92
●	7	1978 CHEVETTE 4 DR. RADIATOR OPEN . WINDOWS CLOSED. FLUSH	7.97

1978 CHEVETTE 4-DOOR
SIDEFORCE. YAWING AND ROLLING MOMENT
CHARACTERISTICS

PAGE
FIGURE

LSWT 291
DATE 11-07-78

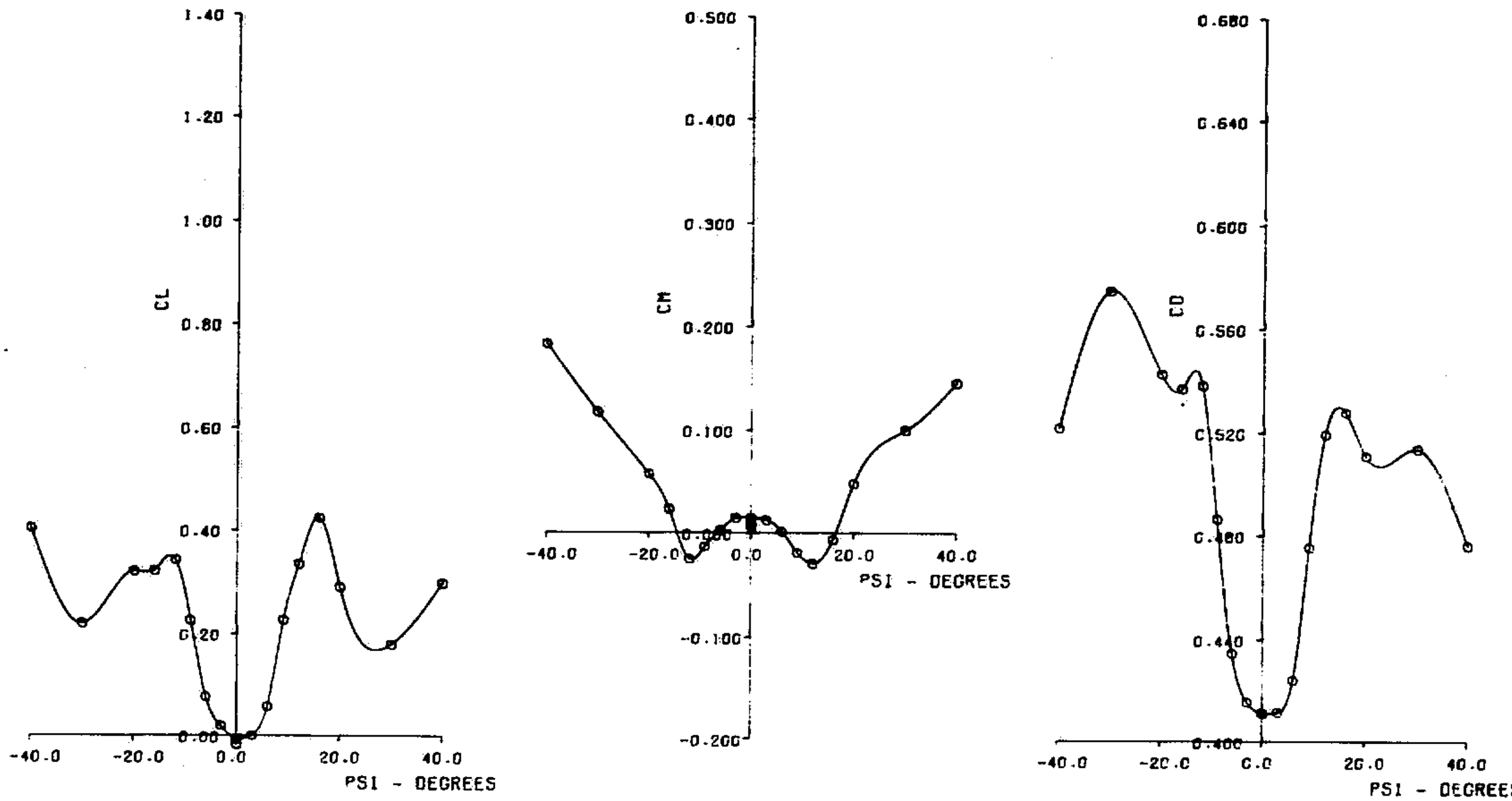


SYM	RUN	CONFIGURATION	Q PSF
⊙	8	1978 HORIZON 4 DR., RADIATOR BLOCKED, WINDOWS CLOSED, FLUSH	7.92

1978 HORIZON 4-DOOR
LIFT, PITCHING MOMENT, AND DRAG
CHARACTERISTICS

PAGE
FIGURE

LSWT 291
DATE 11-07-78

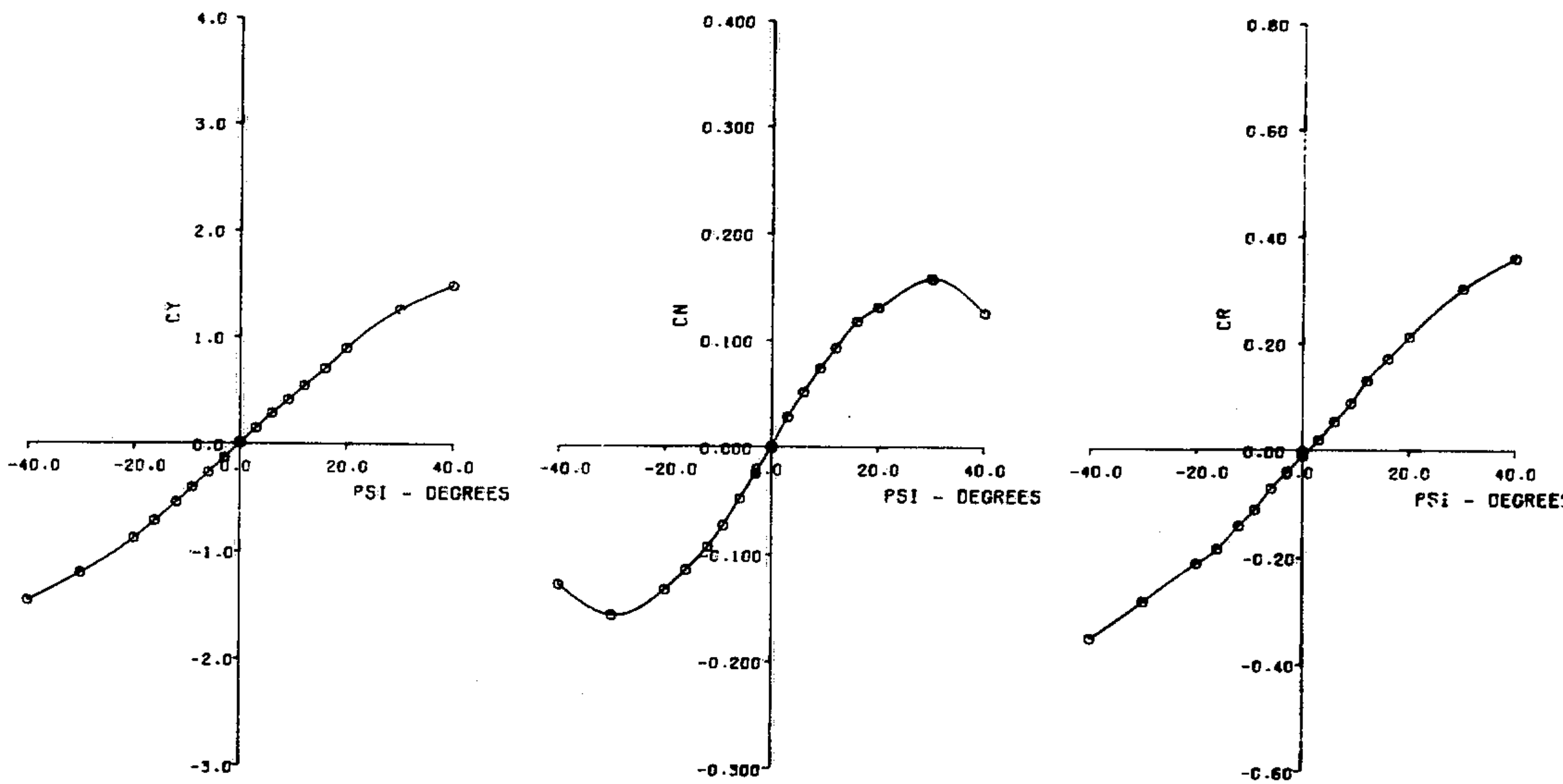


SYM	RUN	CONFIGURATION	Q PSF
○	8	1978 HORIZON 4 DR., RADIATOR BLOCKED, WINDOWS CLOSED, FLUSH	7.92

1978 HORIZON 4-DOOR
SIDEFORCE, YAWING AND ROLLING MOMENT CHARACTERISTICS

PAGE
FIGURE

LSWT 291
DATE 11-07-78

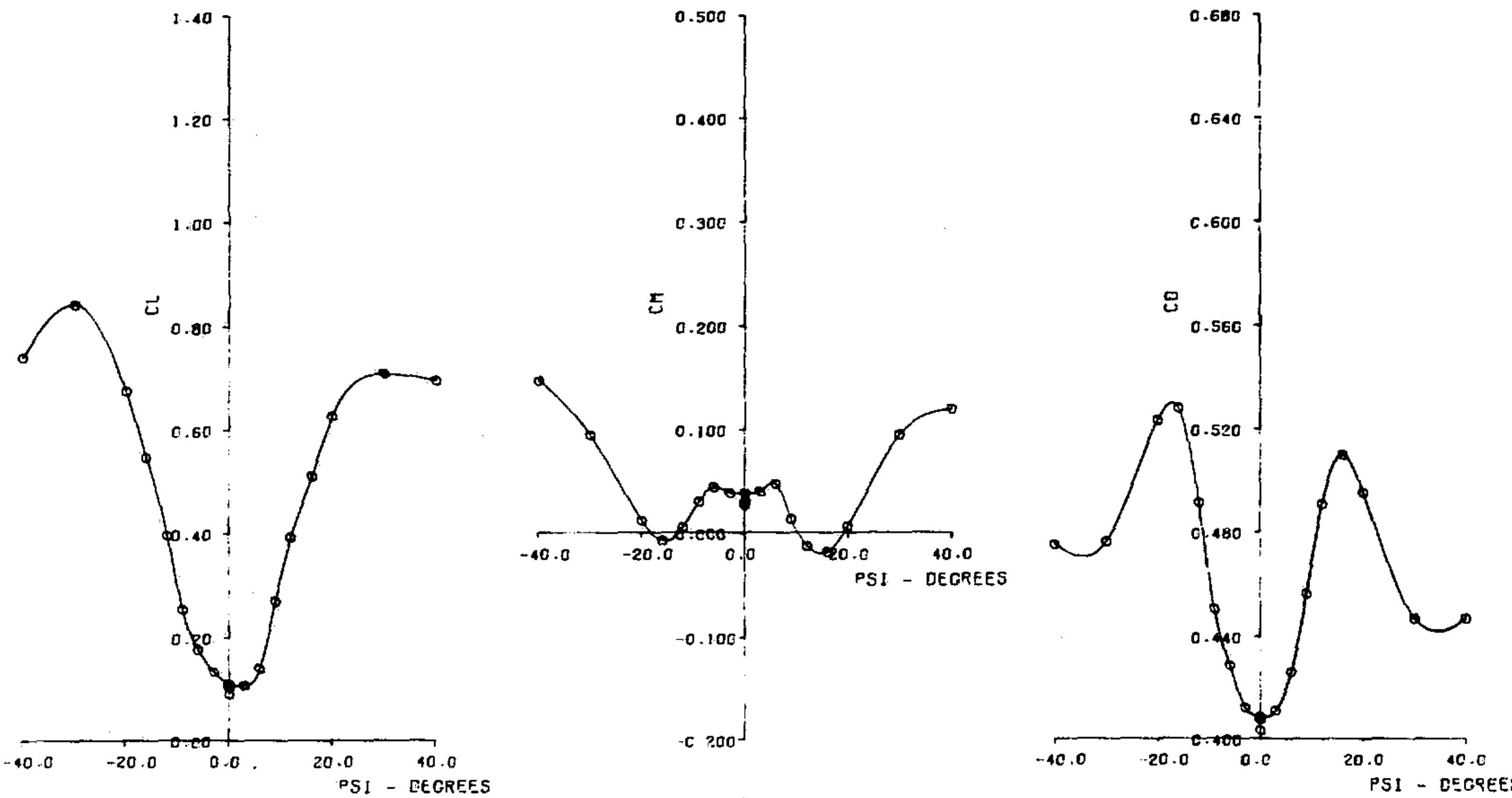


SYM	RUN	CONFIGURATION	Q PSF
O	9	1978 PACER WAGON RADIATOR BLOCKED, WINDOWS CLOSED, FLUSH	8.00

1978 PACER WAGON
LIFT, PITCHING MOMENT, AND DRAG CHARACTERISTICS

PAGE
FIGURE

LSWT 291
DATE 11-07-78

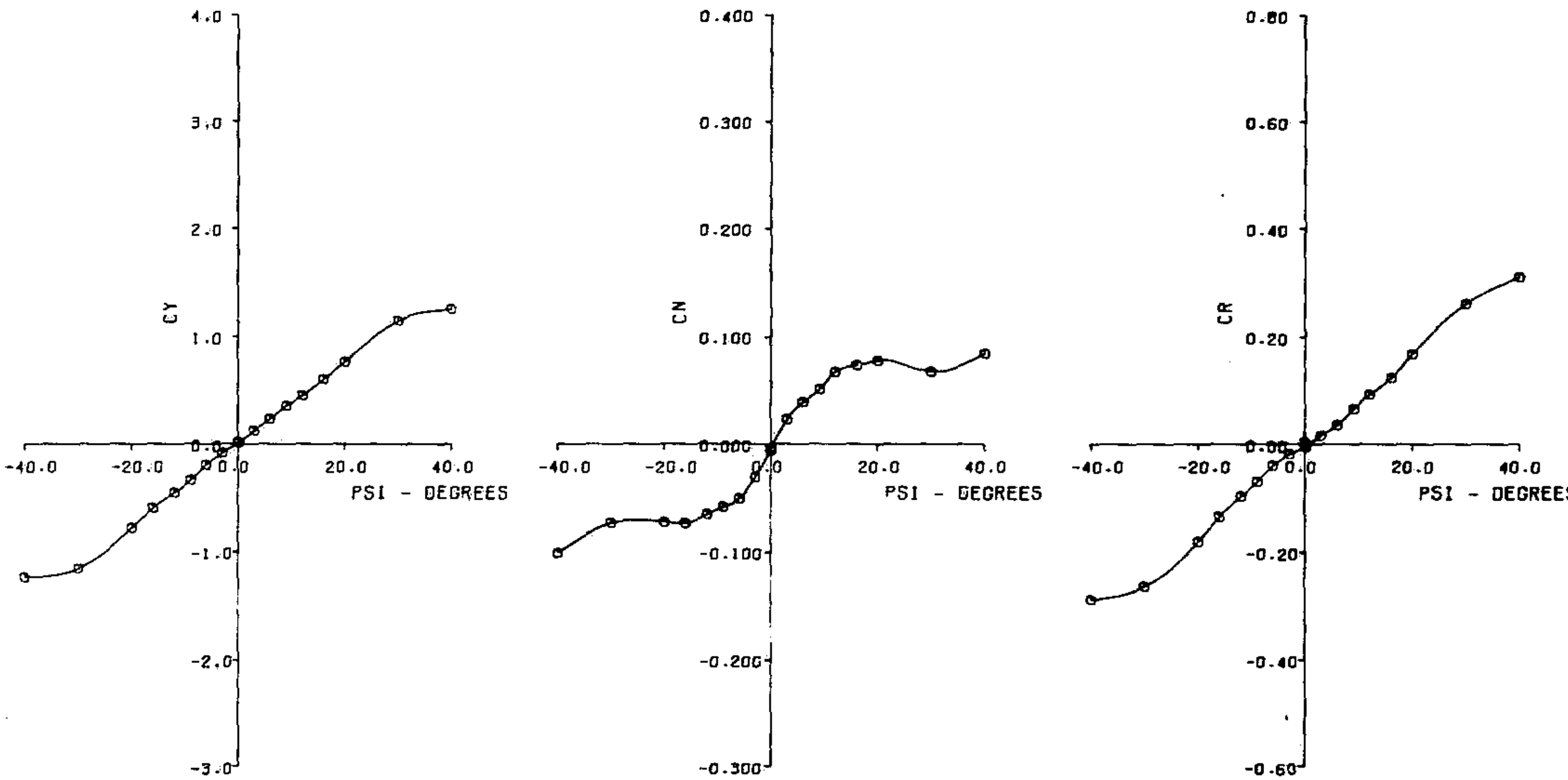


SYM	RUN	CONFIGURATION		Q PSF
○	9	1978 PACER WAGON	RADIATOR BLOCKED. WINDOWS CLOSED. FLUSH	8.00

1978 PACER WAGON
SIDEFORCE, YAWING AND ROLLING MOMENT CHARACTERISTICS

PAGE
FIGURE

LSWT 391
DATE 11-07-78

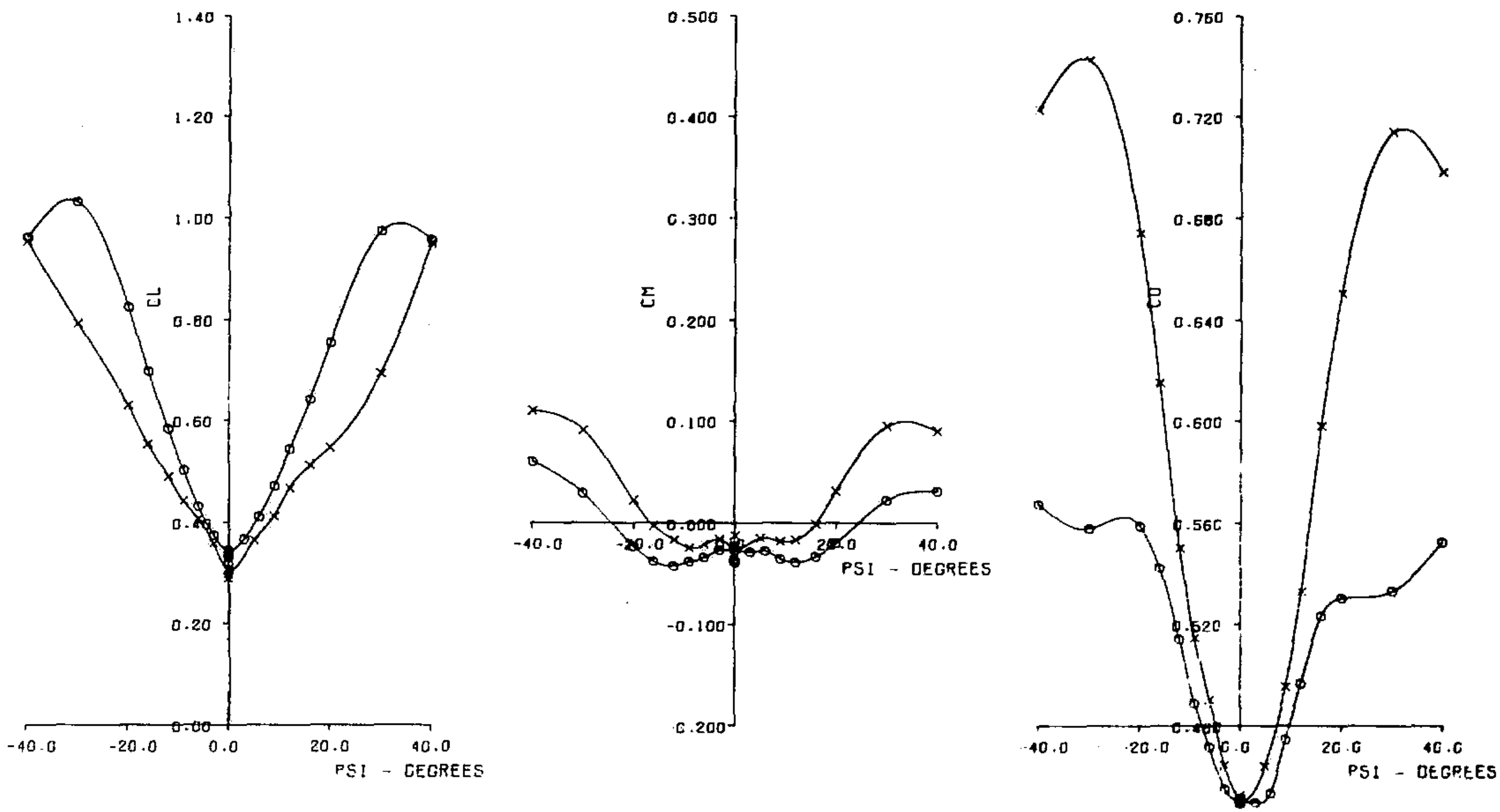


SYM	RUN	CONFIGURATION	Q PSF
o	10	1978 PACER SEDAN RADIATOR BLOCKED, WINDOWS CLOSED, FLUSH	8.03
x	11	1978 PACER SEDAN RADIATOR BLOCKED, WINDOWS OPEN , FLUSH	7.96

1978 PACER SEDAN
LIFT, PITCHING MOMENT, AND DRAG CHARACTERISTICS

PAGE
FIGURE

LSWT 291
DATE 11-07-78



SYM	RUN	CONFIGURATION	Q PSF
o	10	1978 PACER SEDAN RADIATOR BLOCKED, WINDOWS CLOSED, FLUSH	8.03
x	11	1978 PACER SEDAN RADIATOR BLOCKED, WINDOWS OPEN , FLUSH	7.96

1978 PACER SEDAN
SIDEFORCE, YAWING AND ROLLING MOMENT
CHARACTERISTICS

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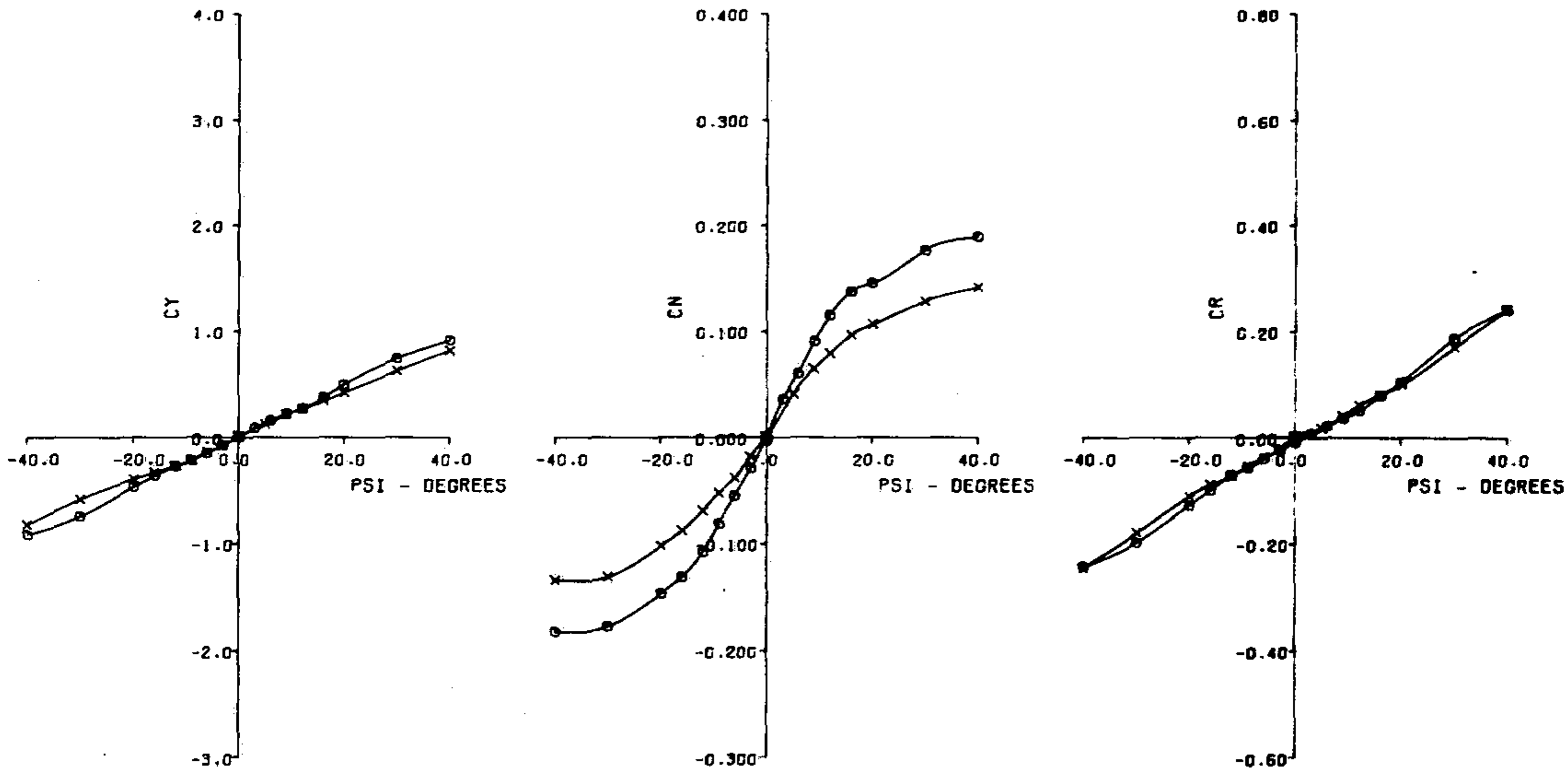
FIGURE

LSWT 29'
DATE 11-07-78

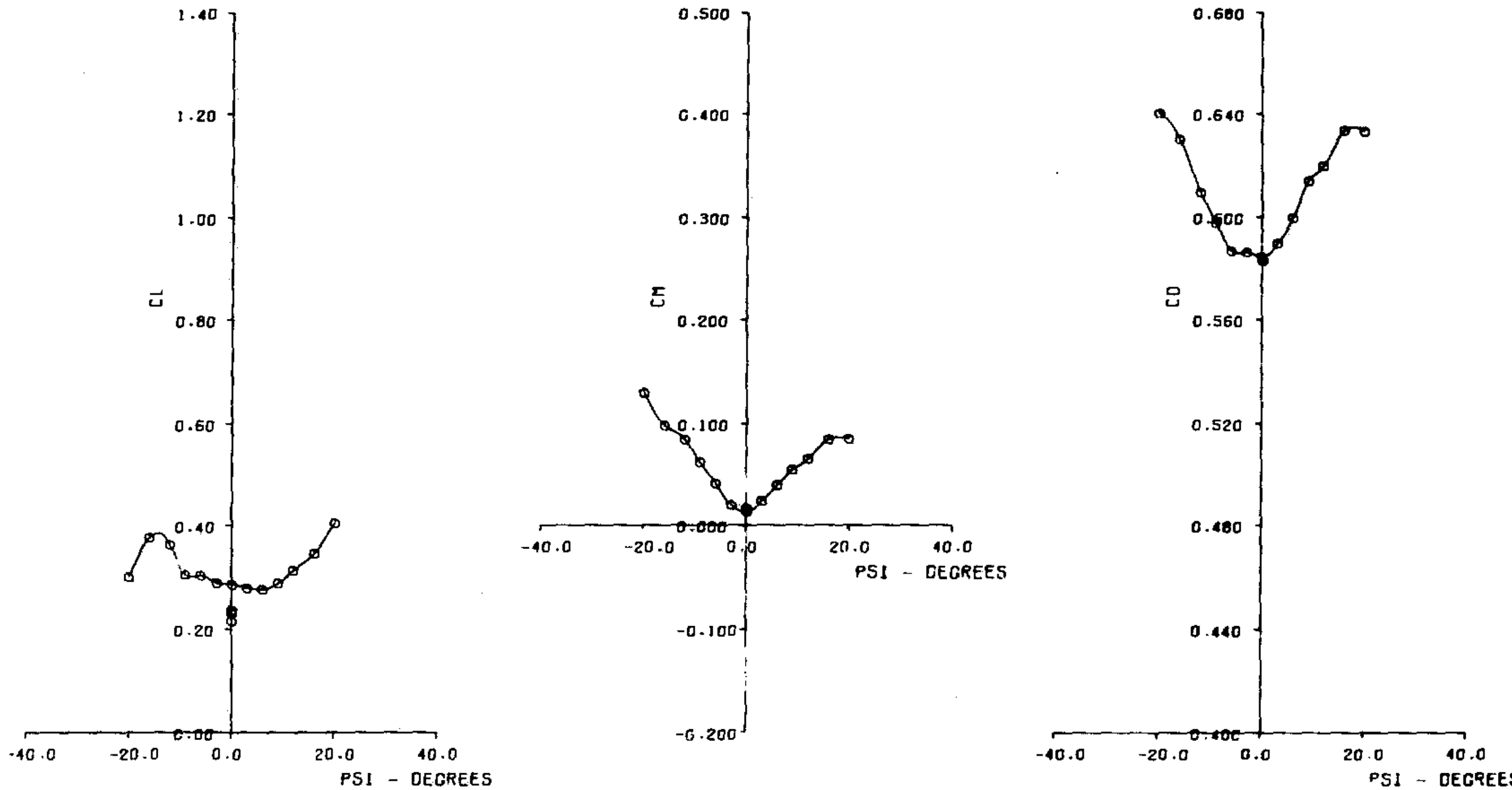


SYM	RUN	CONFIGURATION	Q PSF
○	12	KAYLOR RADIATOR N.A. , WINDOWS N.A. , FLUSH	7.93

KAYLOR
LIFT, PITCHING MOMENT, AND DRAG CHARACTERISTICS

PAGE
FIGURE

LSWT 291
DATE 11-07-78

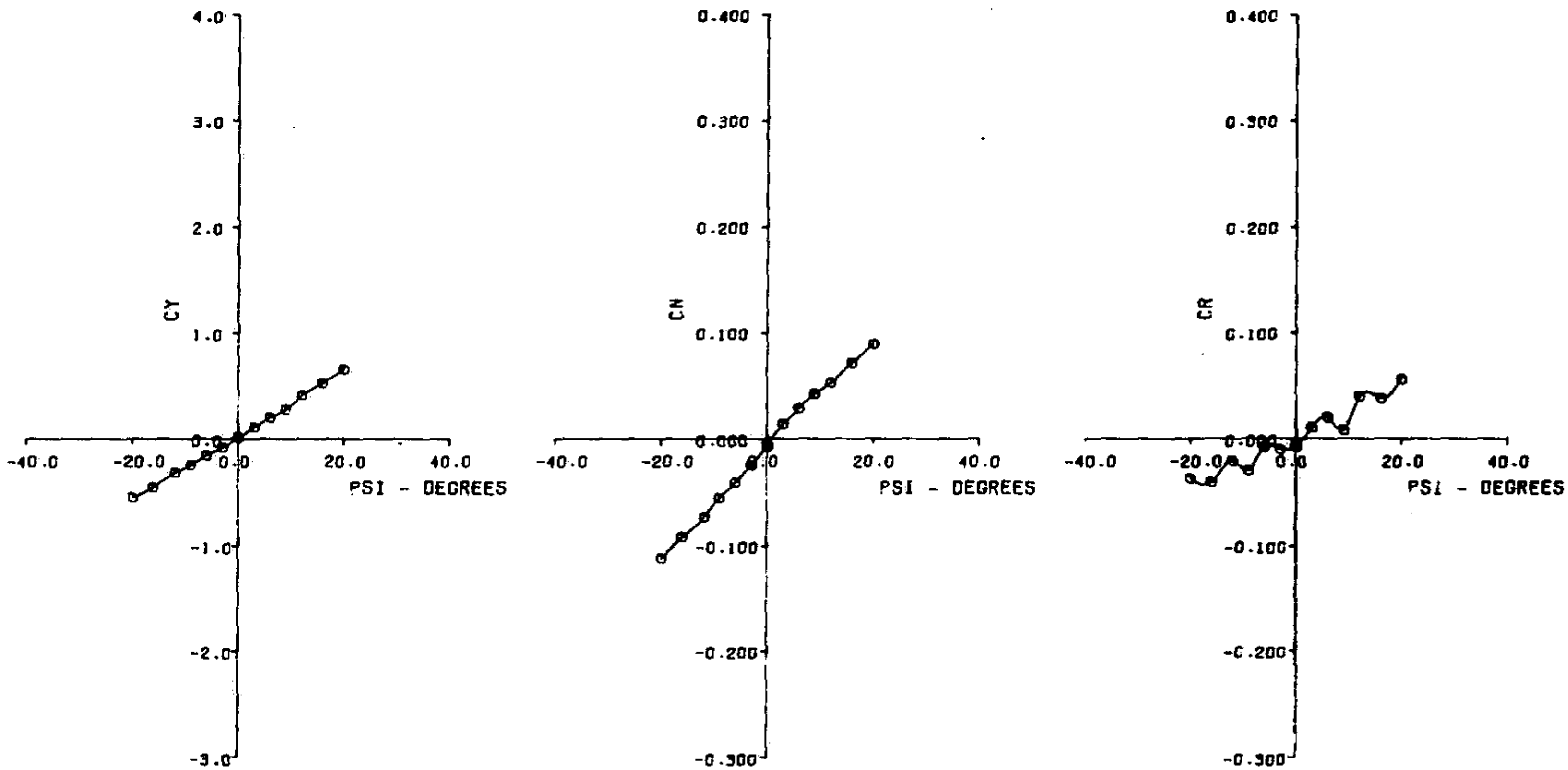


SYM	RUN	CONFIGURATION	Q PSF
O	12	KAYLOR RADIATOR N.R. , WINDOWS N.R. , FLUSH	7.99

KAYLOR
SIDEFORCE, YAWING AND ROLLING MOMENT CHARACTERISTICS

PAGE
FIGURE

LSWT 291
DATE 11-07-78

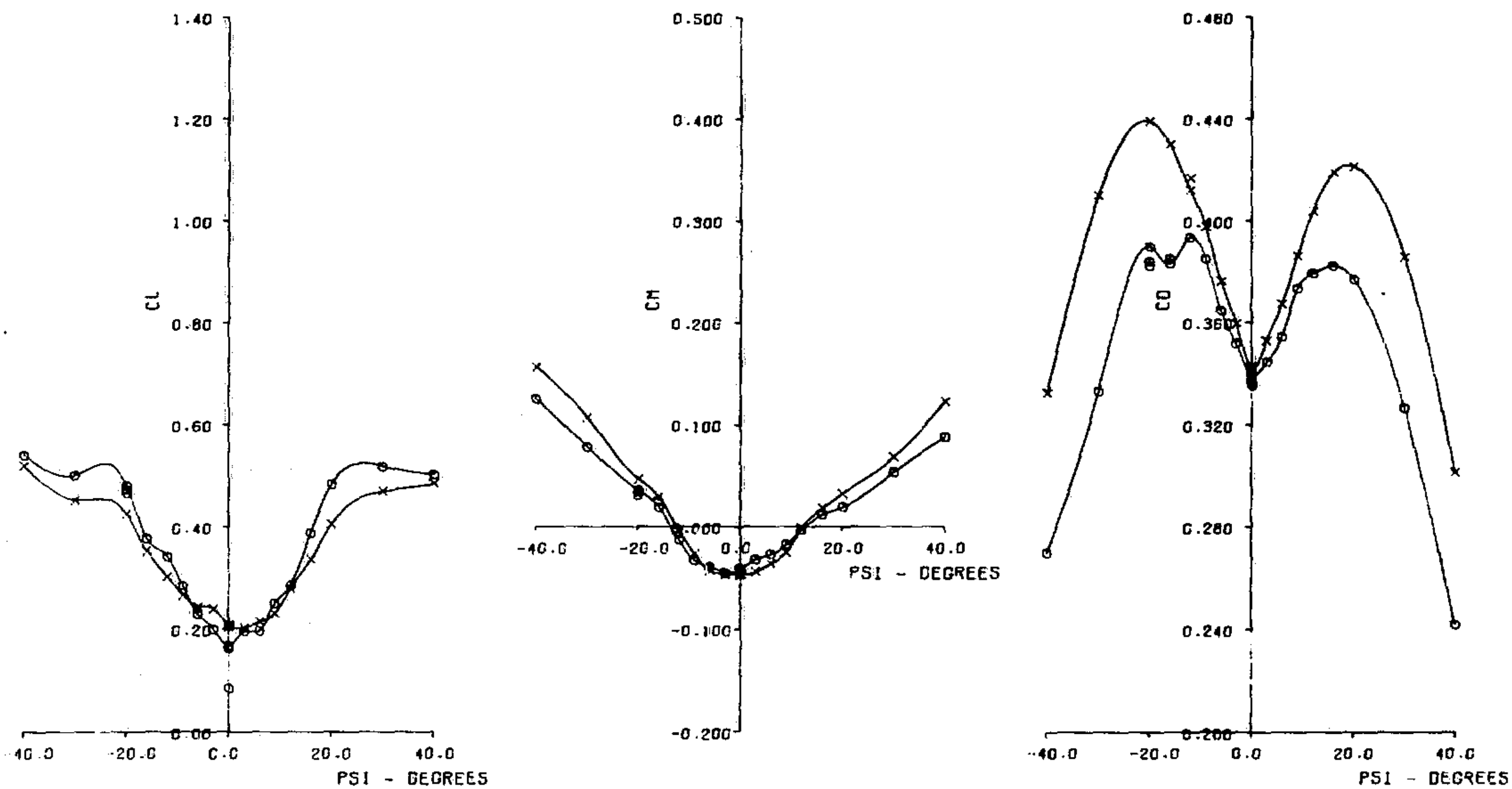


SYM	RUN	CONFIGURATION				Q PSF
○	13	GE REFERENCE	RADIATOR	N.A.	. WINDOWS CLOSED. FLUSH	7.91
×	14	GE REFERENCE	RADIATOR	N.A.	. WINDOWS OPEN . FLUSH	7.92

GE REFERENCE
LIFT. PITCHING MOMENT. AND DRAG
CHARACTERISTICS

PAGE
FIGURE

LSWT 291
DATE 11-07-78



SYM	RUN	CONFIGURATION	Q PSF
o	13	GE REFERENCE RADIATOR N.P. , WINDOWS CLOSED, FLUSH	7.91
x	14	GE REFERENCE RADIATOR N.A. , WINDOWS OPEN , FLUSH	7.92

GE REFERENCE
SIDEFORCE, YAWING AND ROLLING MOMENT CHARACTERISTICS

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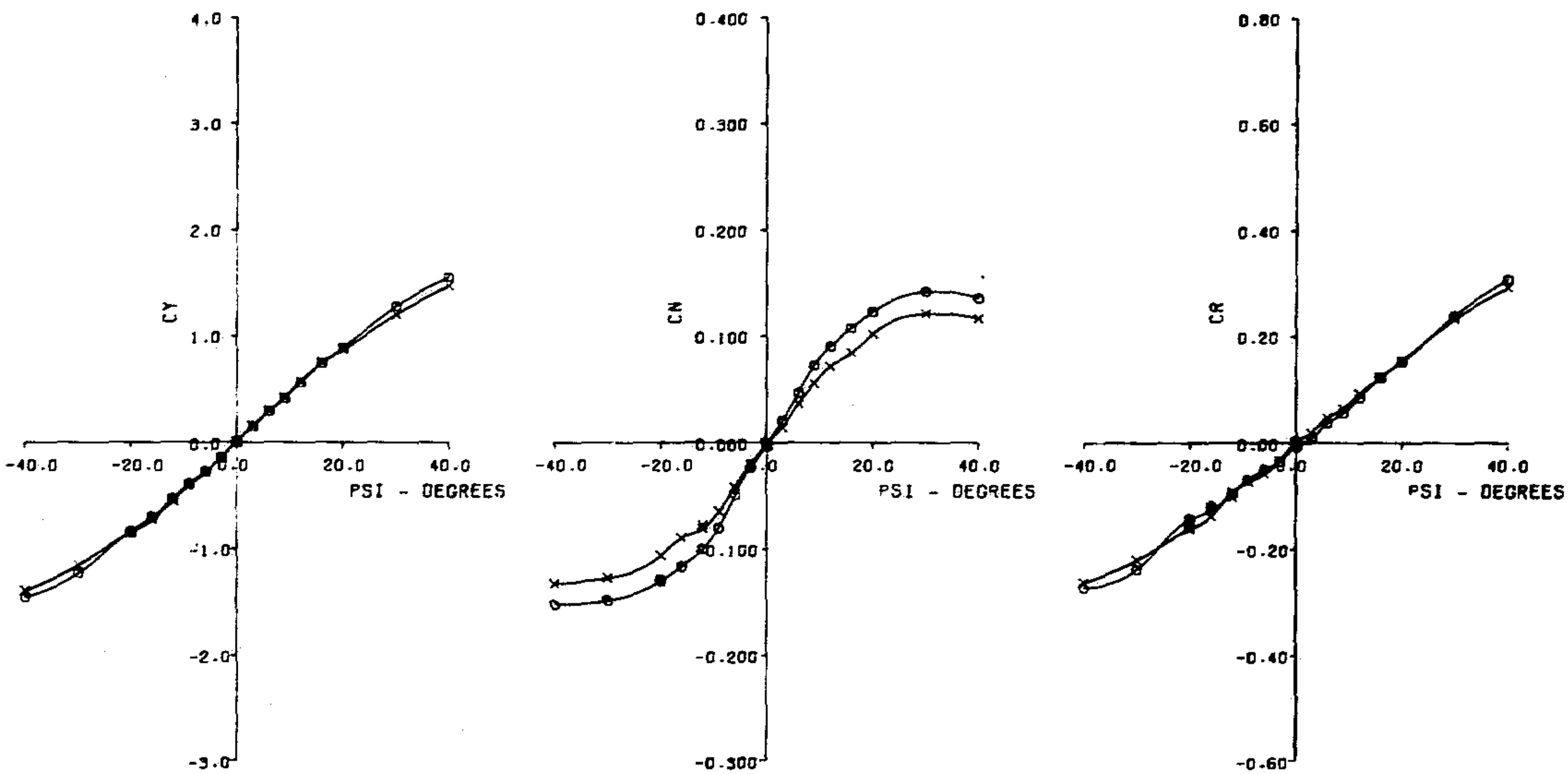
FIGURE

LSWT 291
DATE 11-07-78

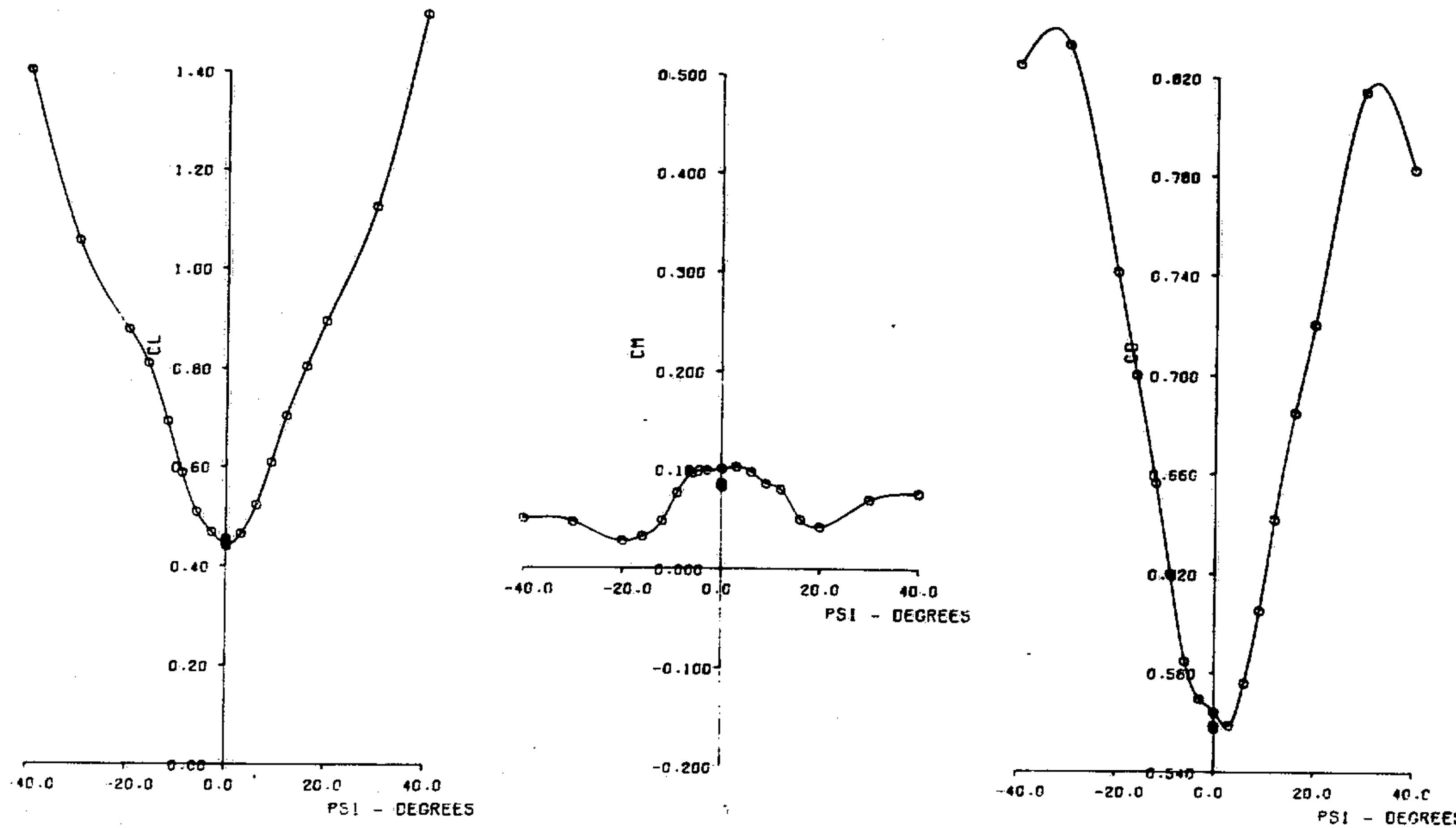


SYM	RUN	CONFIGURATION	Q PSF
O	15	1978 DELTA 88 SEDAN RADIATOR OPEN , WINDOWS CLOSED, FLUSH	8.04

1978 DELTA 88 SEDAN
LIFT, PITCHING MOMENT, AND DRAG CHARACTERISTICS

PAGE
FIGURE

LSWT 291
DATE 11-07-78

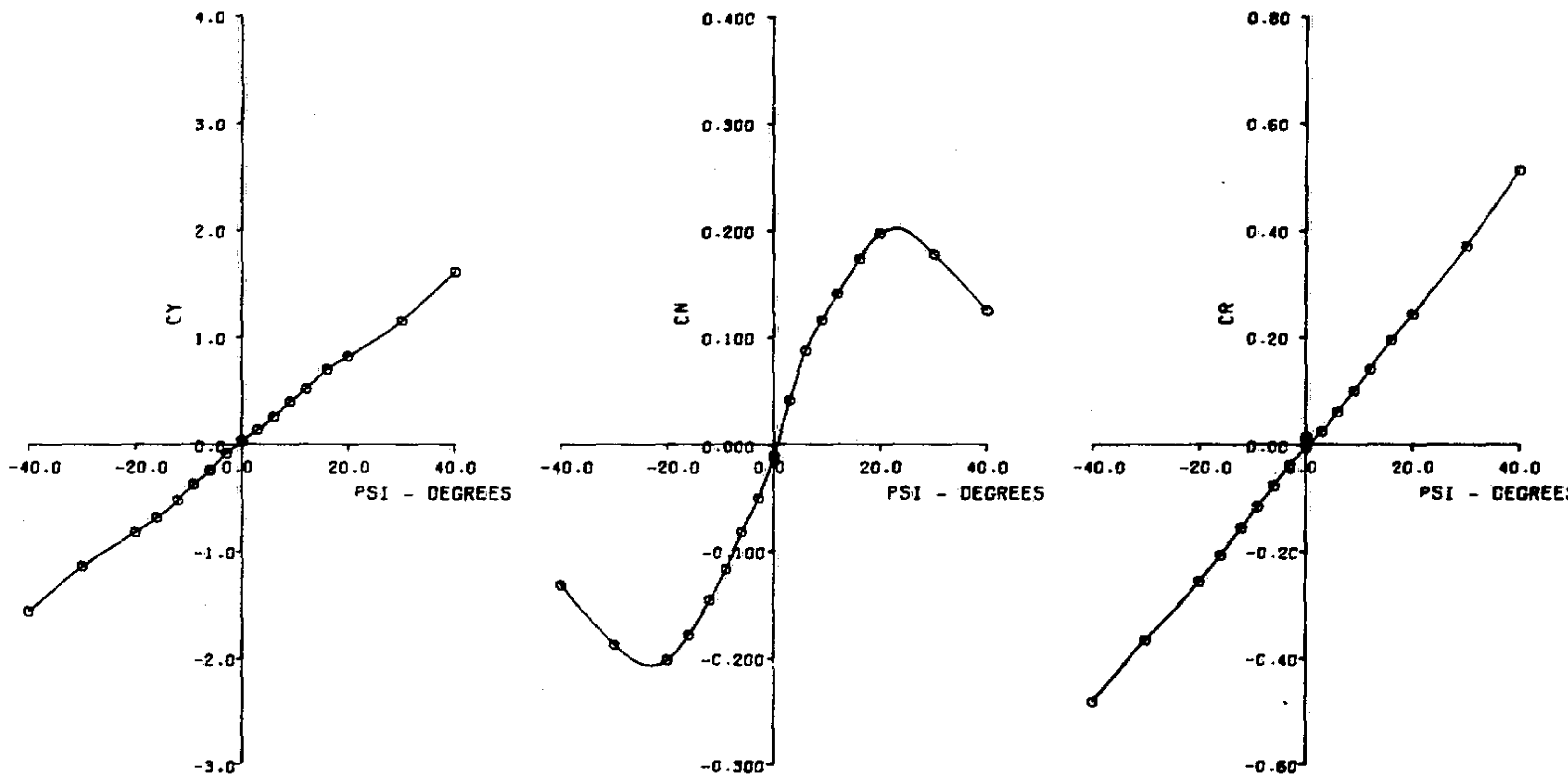


SYM	RUN	CONFIGURATION	Q PSF
○	15	1978 DELTA 88 SEDAN RADIATOR OPEN . WINDOWS CLOSED, FLUSH	8.04

1978 DELTA 88 SEDAN
SIDEFORCE, YAWING AND ROLLING MOMENT
CHARACTERISTICS

PAGE
FIGURE

LSWT 291
DATE 11-07-78

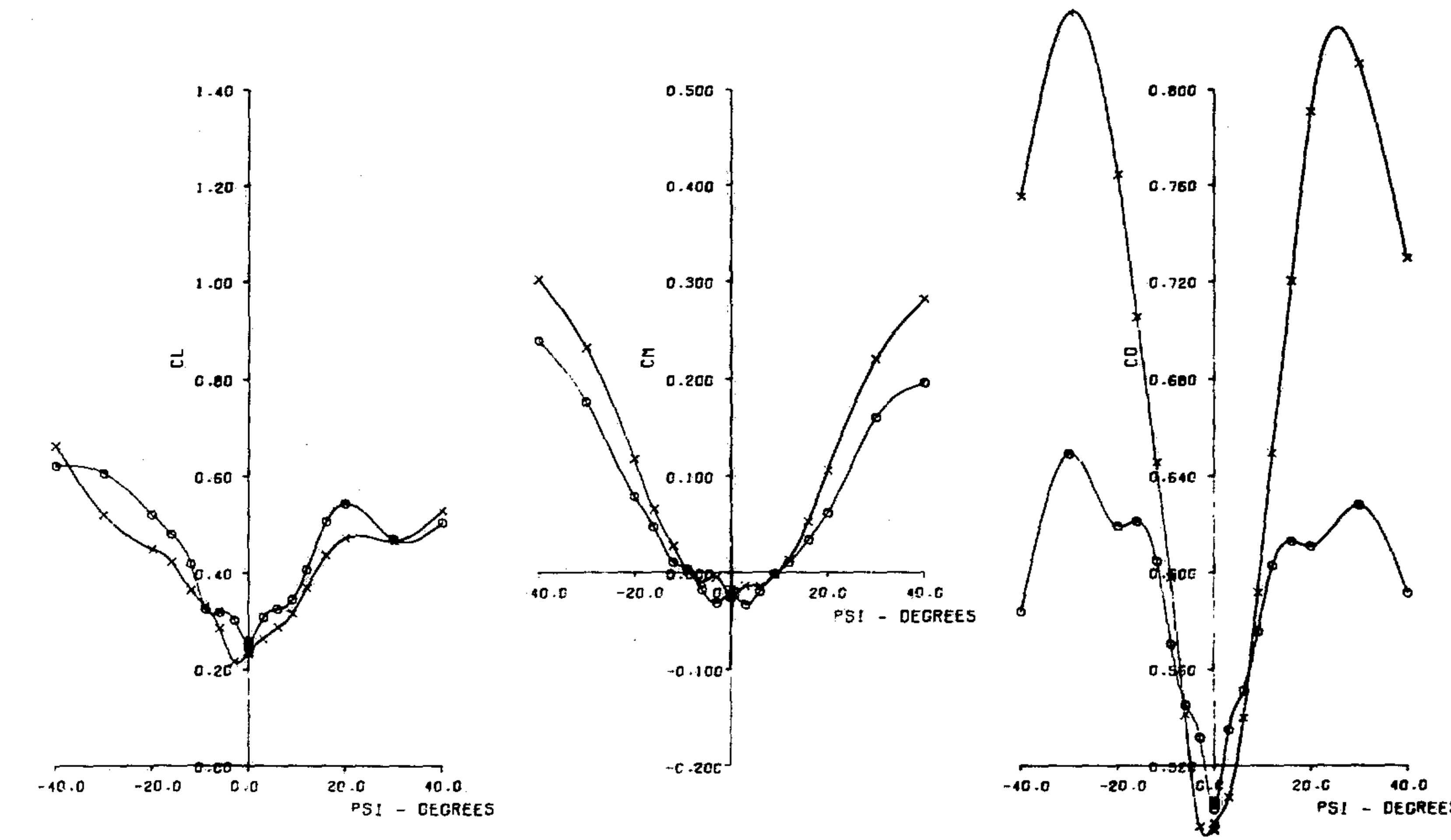


SYM	RUN	CONFIGURATION	Q PSF
O	16	78 HONDA CIVIC SEDAN RADIATOR BLOCKED. WINDOWS CLOSED.10 RAD	7.00
X	17	78 HONDA CIVIC SEDAN RADIATOR BLOCKED. WINDOWS OPEN .10 RAD	7.00

1978 HONDA CIVIC SEDAN
LIFT, PITCHING MOMENT, AND DRAG
CHARACTERISTICS

PAGE
FIGURE

LSWT 291
DATE 11-07-78

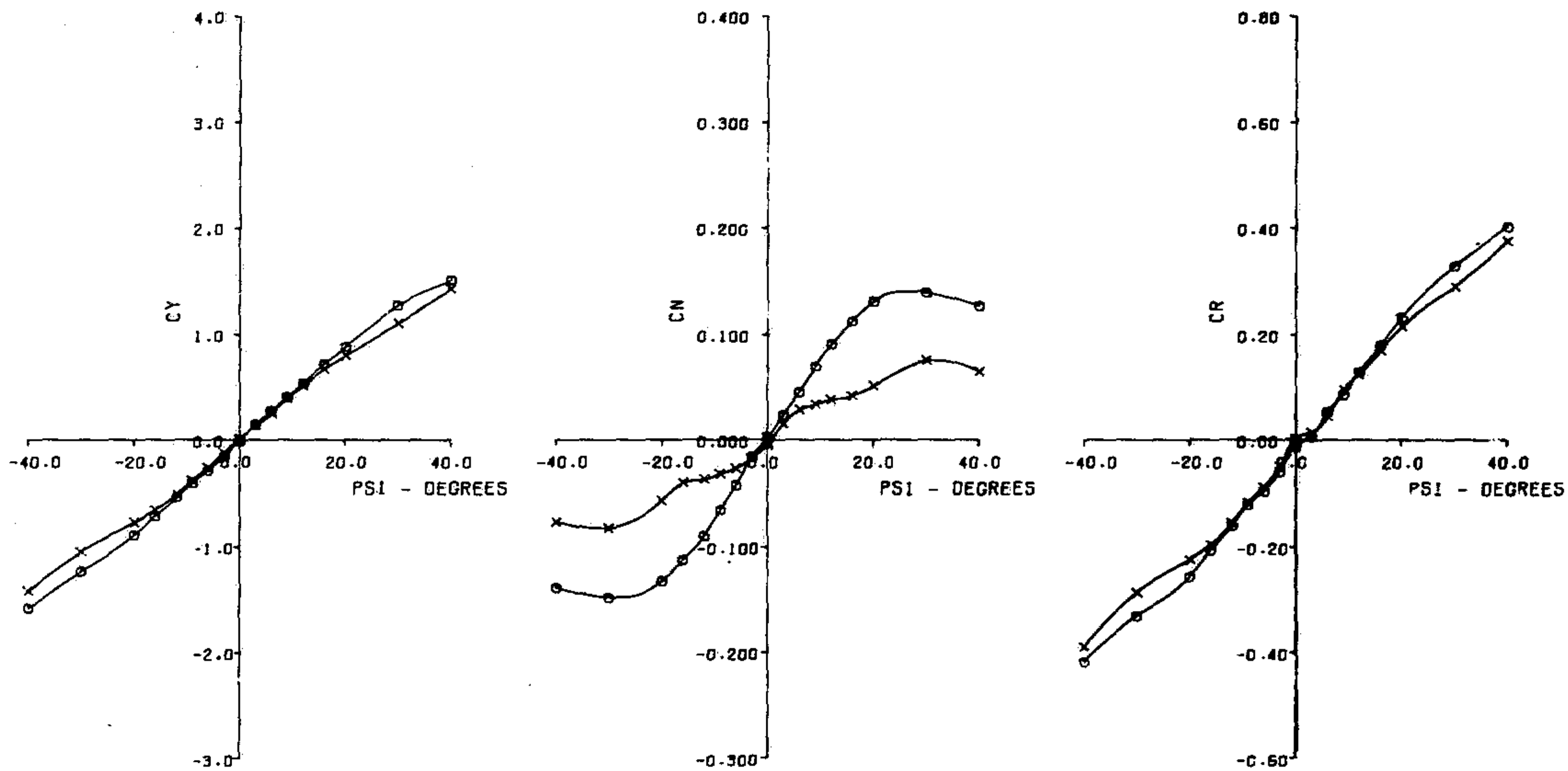


SYM	RUN	CONFIGURATION	Q PSF
⊙	16	78 HONDA CIVIC SEDAN RADIATOR BLOCKED. WINDOWS CLOSED.10 PAD	7.88
×	17	78 HONDA CIVIC SEDAN RADIATOR BLOCKED. WINDOWS OPEN .10 PAD	7.88

1978 HONDA CIVIC SEDAN
SIDEFORCE, YAWING AND ROLLING MOMENT CHARACTERISTICS

PAGE
FIGURE

LSWT 291
DATE 11-07-78

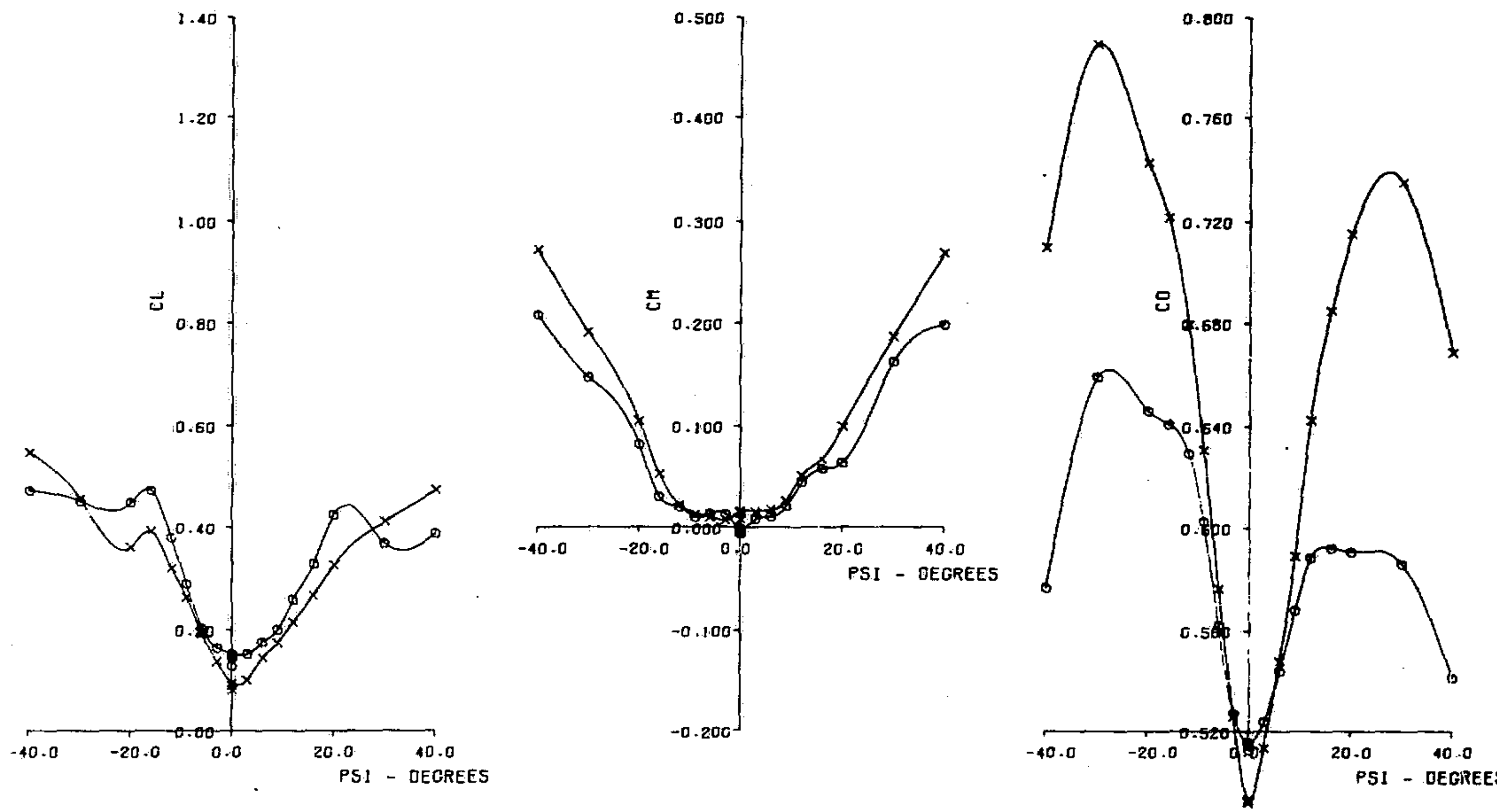


SYM	RUN	CONFIGURATION	Q PSF
o	18	78 HONDA CIVIC WAGON RADIATOR BLOCKED. WINDOWS CLOSED.1* PAD	7.93
x	19	78 HONDA CIVIC WAGON RADIATOR BLOCKED. WINDOWS OPEN .1* PAD	7.94

1978 HONDA CIVIC WAGON
LIFT. PITCHING MOMENT. AND DRAG
CHARACTERISTICS

PAGE
FIGURE

LSWT 291
DATE 11-07-78

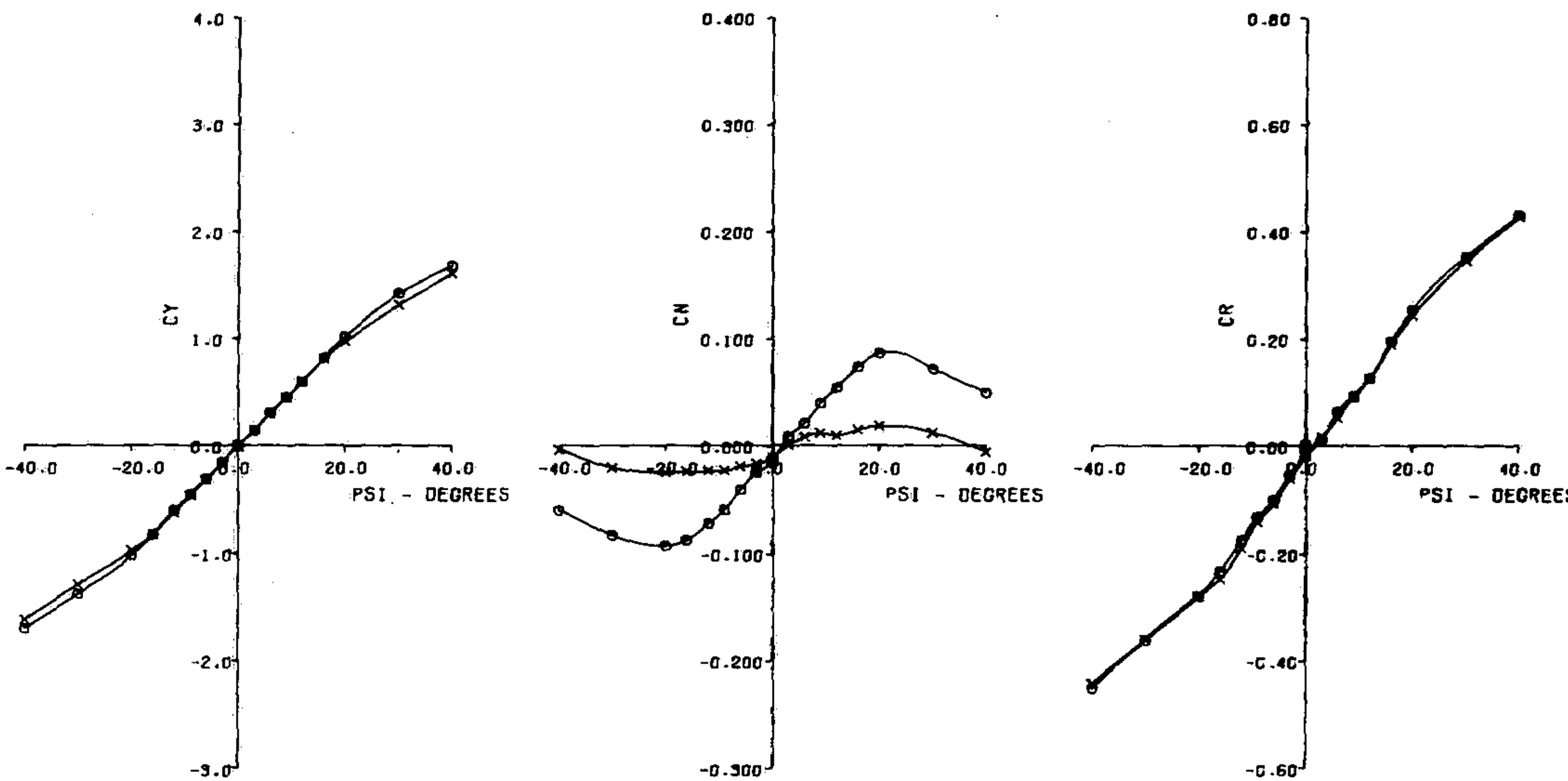


SYM	RUN	CONFIGURATION	Q PSF
O	18	78 HONDA CIVIC WAGON RADIATOR BLOCKED. WINDOWS CLOSED.1° PAD	7.93
X	19	78 HONDA CIVIC WAGON RADIATOR BLOCKED. WINDOWS OPEN .1° PAD	7.94

1978 HONDA CIVIC WAGON
SIDEFORCE, YAWING AND ROLLING MOMENT CHARACTERISTICS

PAGE
FIGURE

LSWT 291
DATE 11-07-78

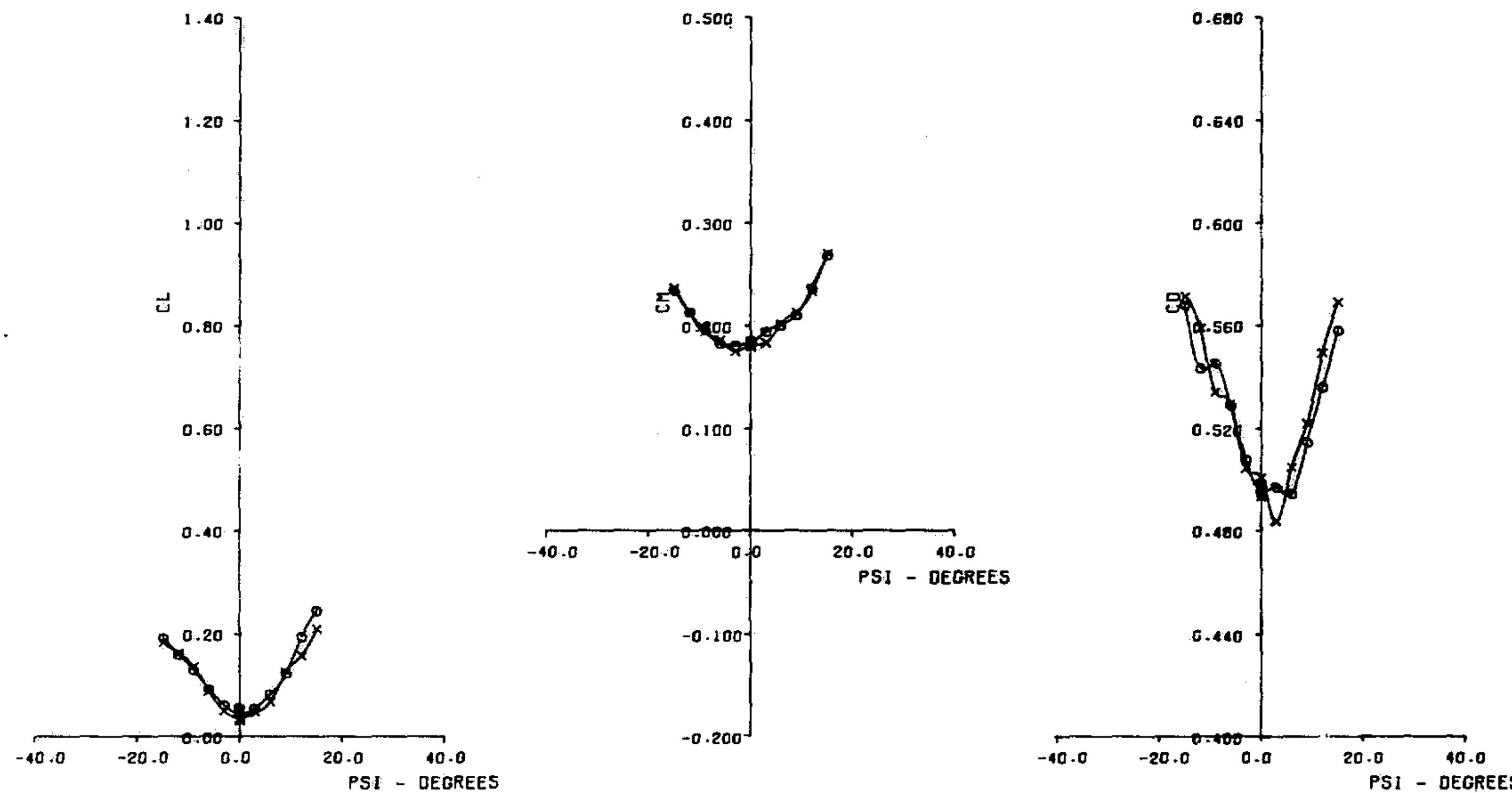


SYM	RUN	CONFIGURATION	Q PSF
O	20	HYBRID ELECTRIC VAN RADIATOR N.A. , WINDOWS CLOSED, FLUSH	8.35
X	21	HYBRID ELECTRIC VAN RADIATOR N.A. , WINDOWS OPEN , FLUSH	8.33

HYBRID ELECTRIC VAN
LIFT, PITCHING MOMENT, AND DRAG
CHARACTERISTICS

PAGE
FIGURE

LSWT 291
DATE 11-07-78

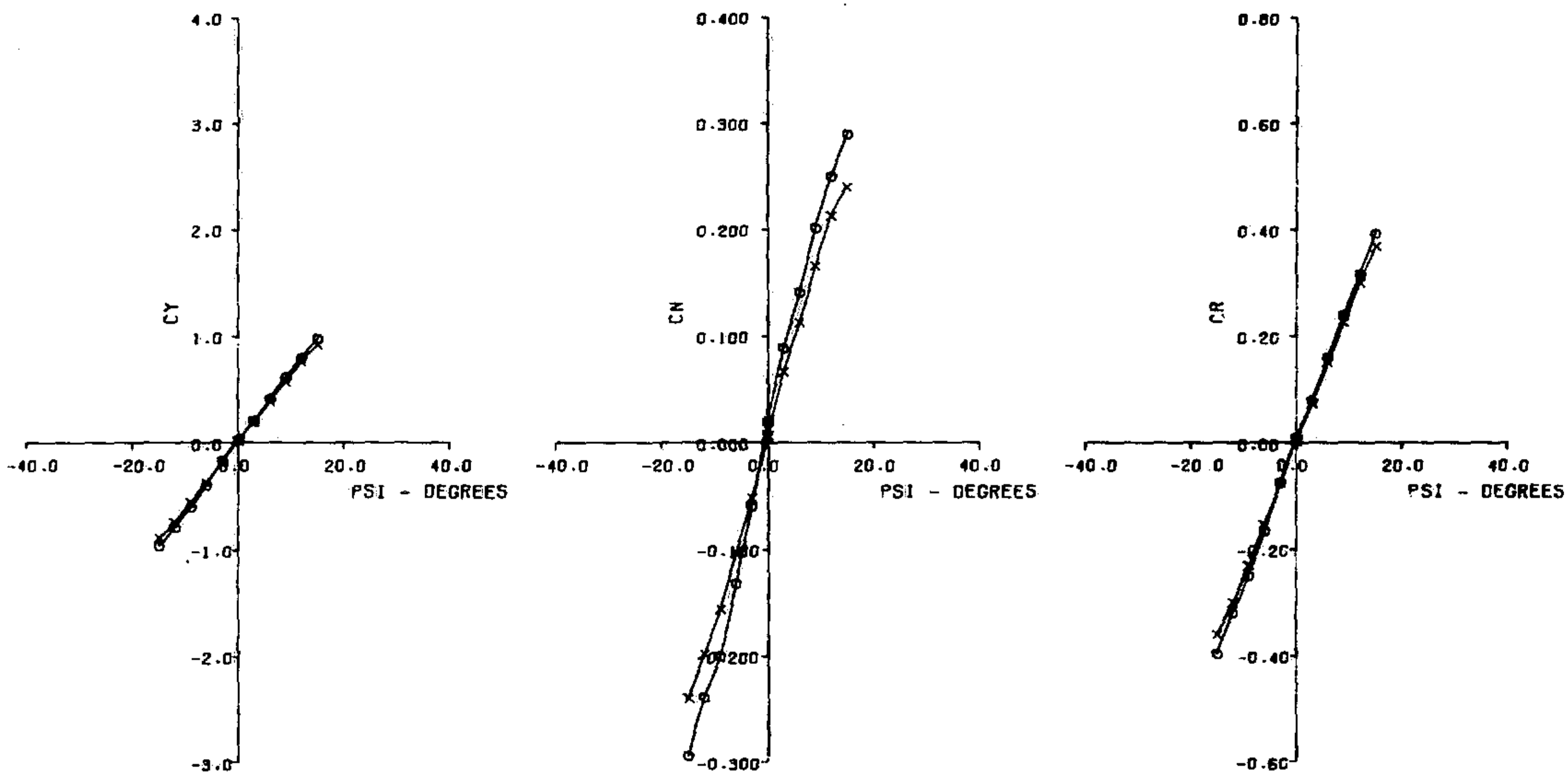


SYM	RUN	CONFIGURATION	Q PSF
o	20	HYBRID ELECTRIC VAN RADIATOR N.A. . WINDOWS CLOSED. FLUSH	8.35
x	21	HYBRID ELECTRIC VAN RADIATOR N.A. . WINDOWS OPEN . FLUSH	8.35

HYBRID ELECTRIC VAN
SIDEFORCE, YAWING AND ROLLING MOMENT CHARACTERISTICS

PAGE
FIGURE

LSWT 291
DATE 11-07-78

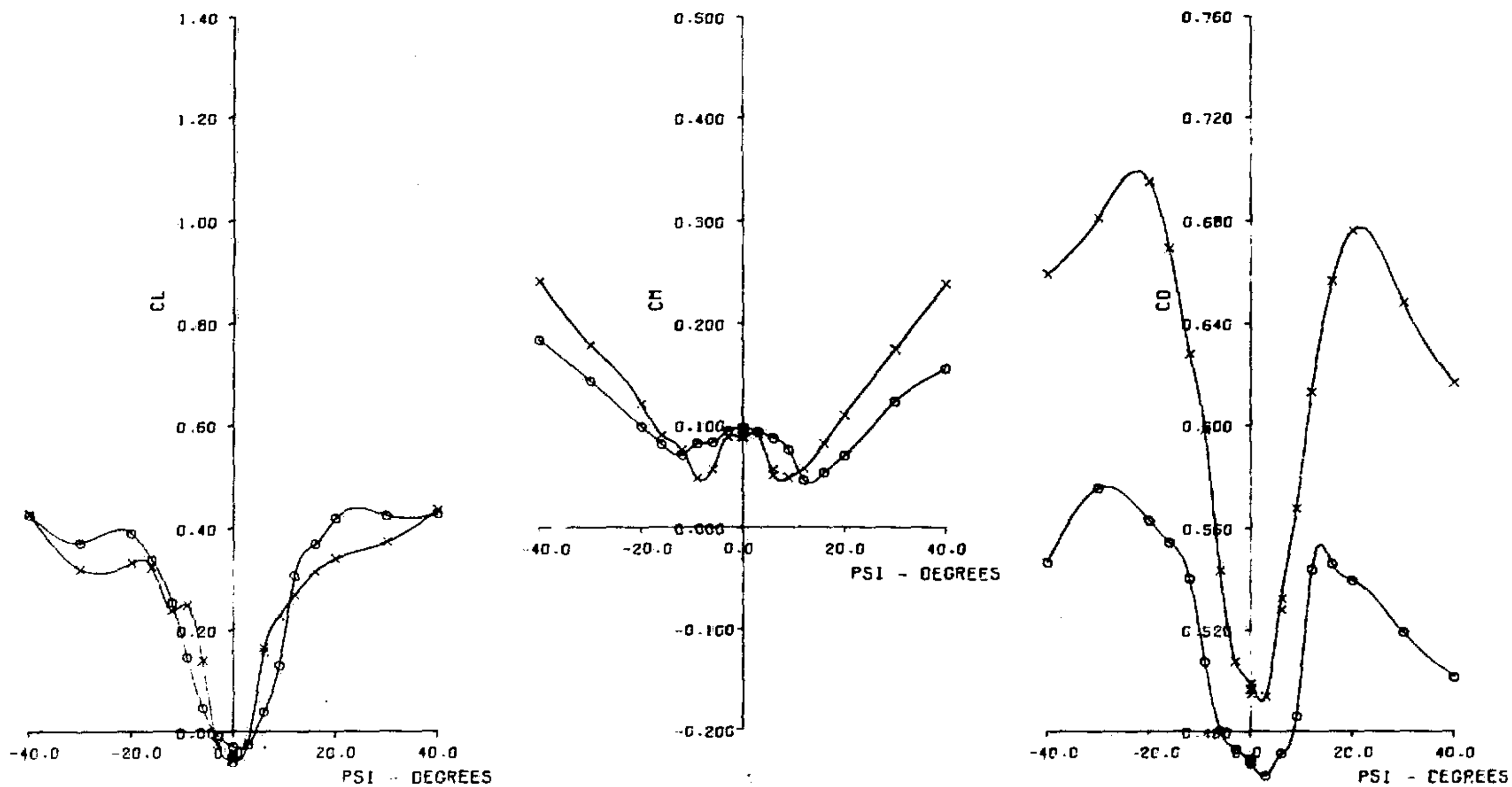


SYM	RUN	CONFIGURATION	Q PSF
o	22	1978 FORD FIESTA RADIATOR BLOCKED. WINDOWS CLOSED..S=PRO	8.27
x	23	1978 FORD FIESTA. RADIATOR BLOCKED. WINDOWS OPEN ..S=PRO	8.30

1978 FORD FIESTA
LIFT, PITCHING MOMENT, AND DRAG CHARACTERISTICS

PAGE
FIGURE

LSWT 291
DATE 11-07-78

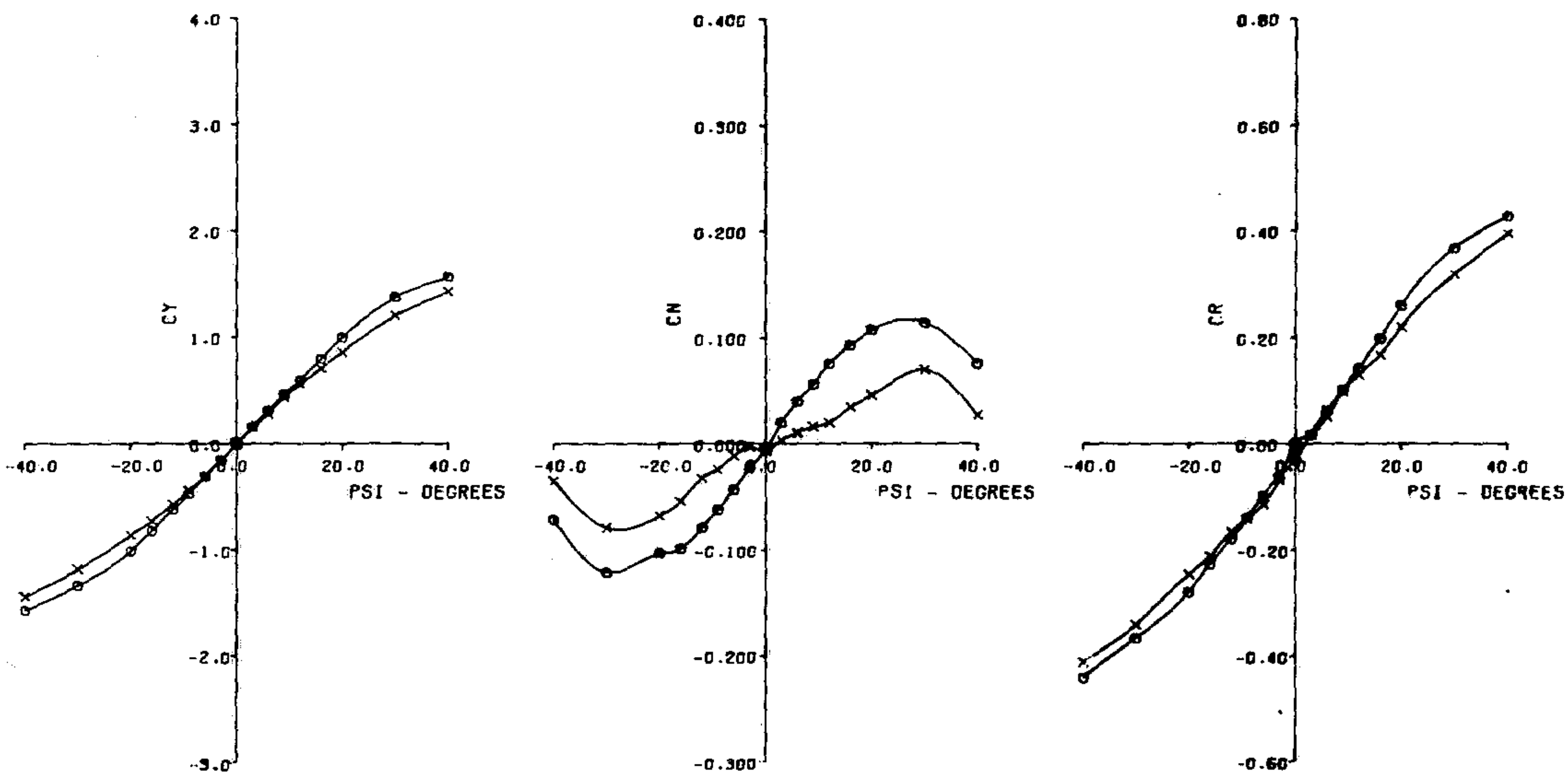


SYM	RUN	CONFIGURATION	Q PSF
o	22	1978 FORD FIESTA RADIATOR BLOCKED, WINDOWS CLOSED..S*PAD	8.27
x	23	1978 FORD FIESTA RADIATOR BLOCKED, WINDOWS OPEN ..S*PAD	8.30

1978 FORD FIESTA
SIDEFORCE, YAWING AND ROLLING MOMENT CHARACTERISTICS

PAGE
FIGURE

TEST 291
DATE 11-07-78



SYM	RUN	CONFIGURATION		Q PSF
O	25	1967 CORVETTE	RADIATOR BLOCKED. WINDOWS CLOSED. FLUSH	7.93
X	26	1967 CORVETTE	RADIATOR BLOCKED. WINDOWS OPEN . FLUSH	7.95
+	27	1967 CORVETTE	RADIATOR BLOCKED. WINDOWS CLOSED. FLUSH	7.97
▲	28	1967 CORVETTE	RADIATOR OPEN . WINDOWS CLOSED. FLUSH	7.97

1967 CORVETTE
LIFT. PITCHING MOMENT. AND DRAG
CHARACTERISTICS

PAGE
FIGURE

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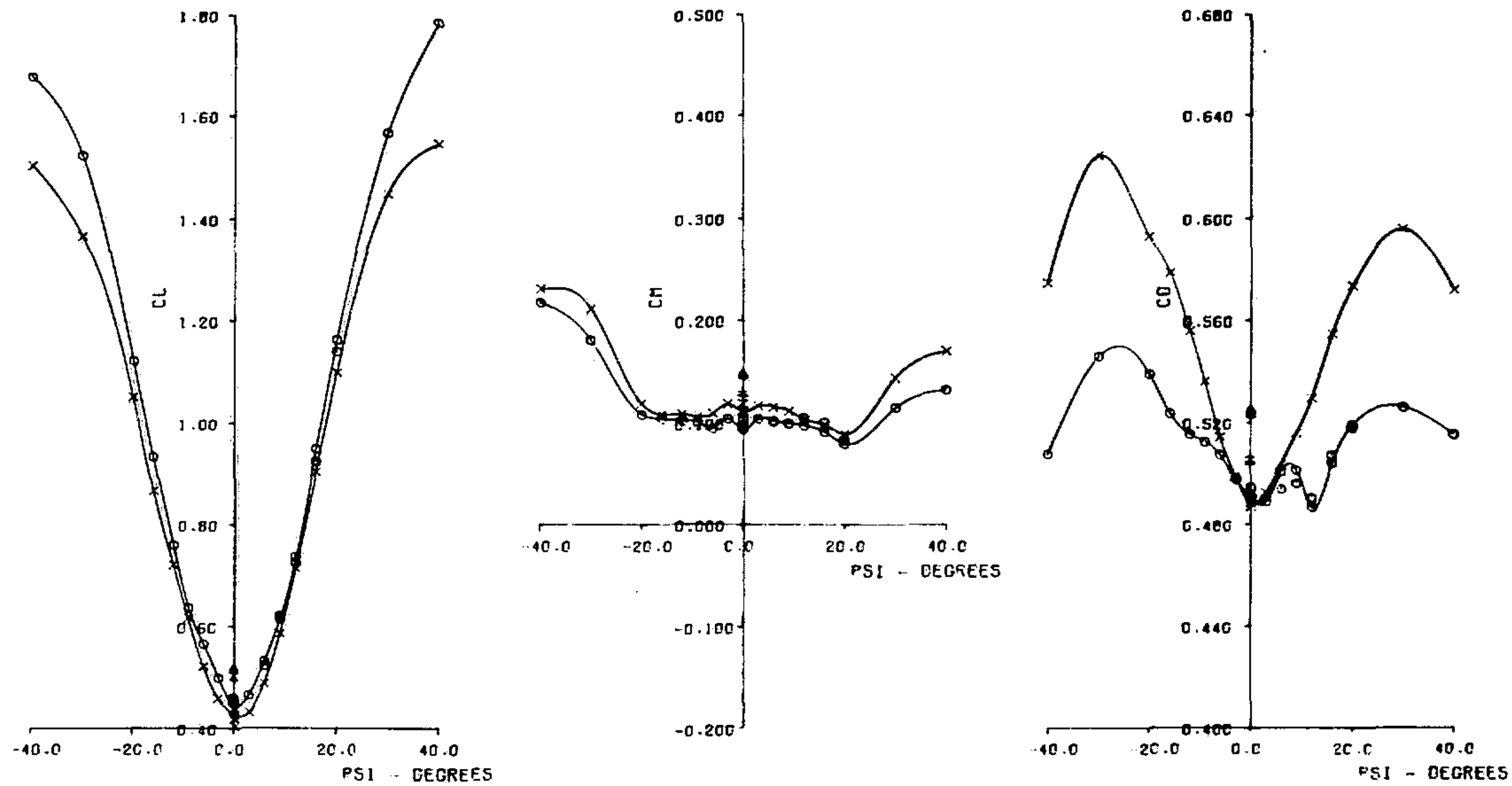

SYM	RUN	CONFIGURATION		Q PSF
⊙	25	1967 CORVETTE	RADIATOR BLOCKED, WINDOWS CLOSED, FLUSH	7.93
×	26	1967 CORVETTE	RADIATOR BLOCKED, WINDOWS OPEN , FLUSH	7.95
⊢	27	1967 CORVETTE	RADIATOR BLOCKED, WINDOWS CLOSED, FLUSH	7.97
◆	28	1967 CORVETTE	RADIATOR OPEN , WINDOWS CLOSED, FLUSH	7.97

1967 CORVETTE
SIDEFORCE, YAWING AND ROLLING MOMENT CHARACTERISTICS

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FIGURE

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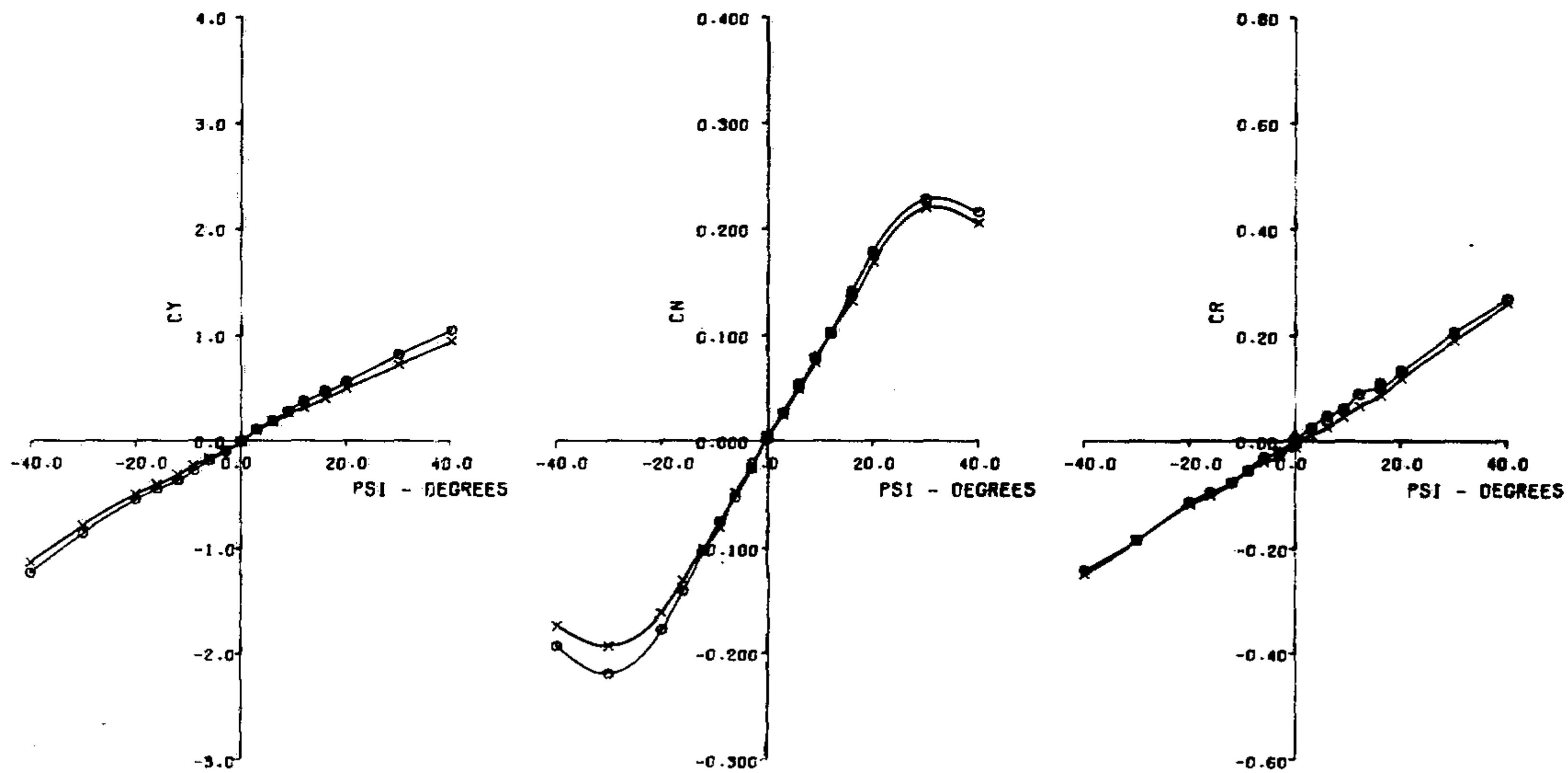

SYM	RUN	CONFIGURATION	Q PSF
O	29	TOWN CAR RADIATOR N.A. , WINDOWS CLOSED,1" PAD	7.88
X	30	TOWN CAR RADIATOR N.A. , WINDOWS OPEN ,1" PAD	7.89

TOWN CAR
LIFT, PITCHING MOMENT, AND DRAG
CHARACTERISTICS

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FIGURE

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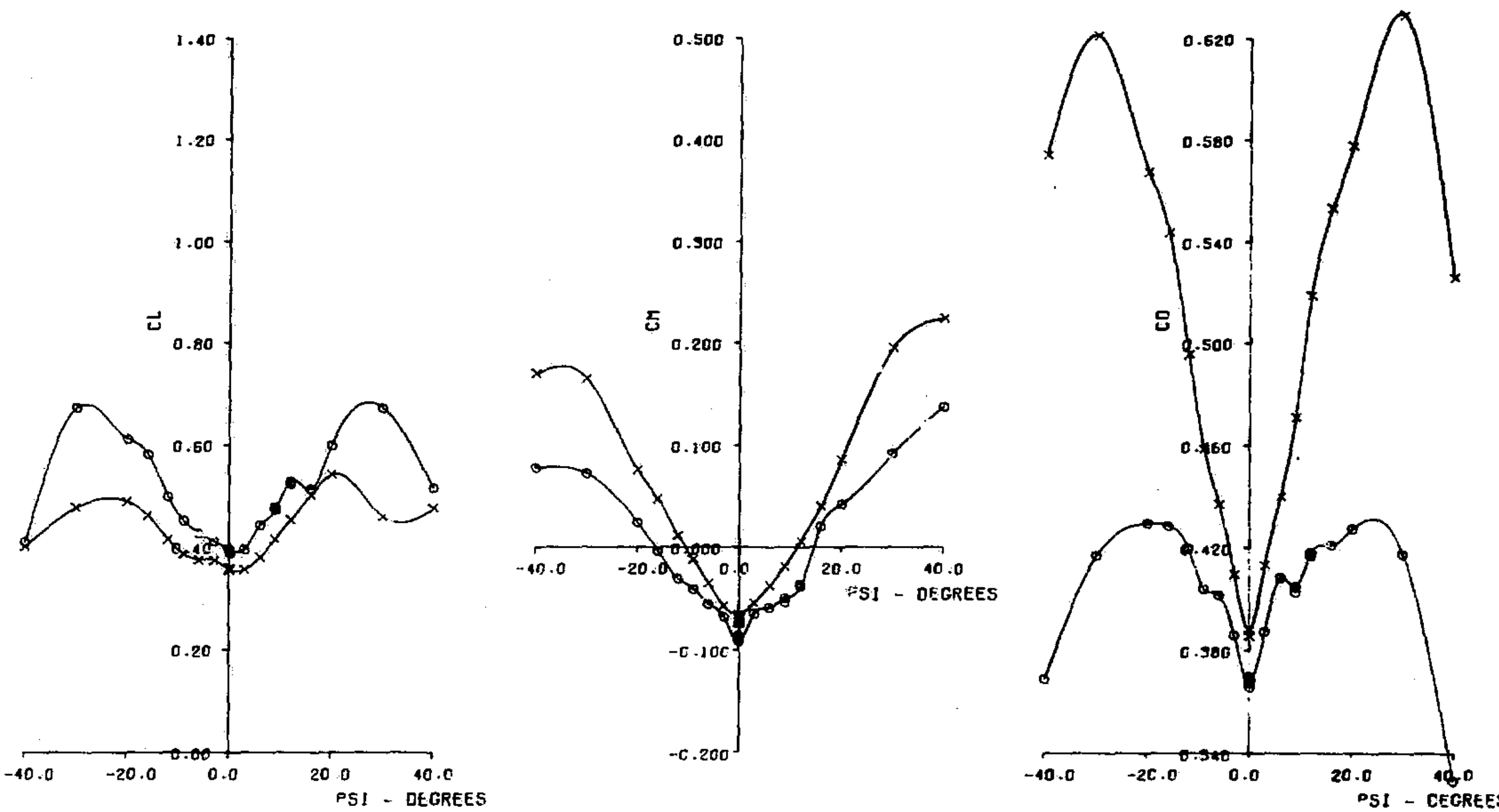

SYM	RUN	CONFIGURATION	Q PSF
⊙	29	TOWN CAR RADIATOR N.A. , WINDOWS CLOSED,10 PAD	7.88
×	30	TOWN CAR RADIATOR N.A. , WINDOWS OPEN ,10 PAD	7.89

TOWN CAR
SIDEFORCE, YAWING AND ROLLING MOMENT
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FIGURE

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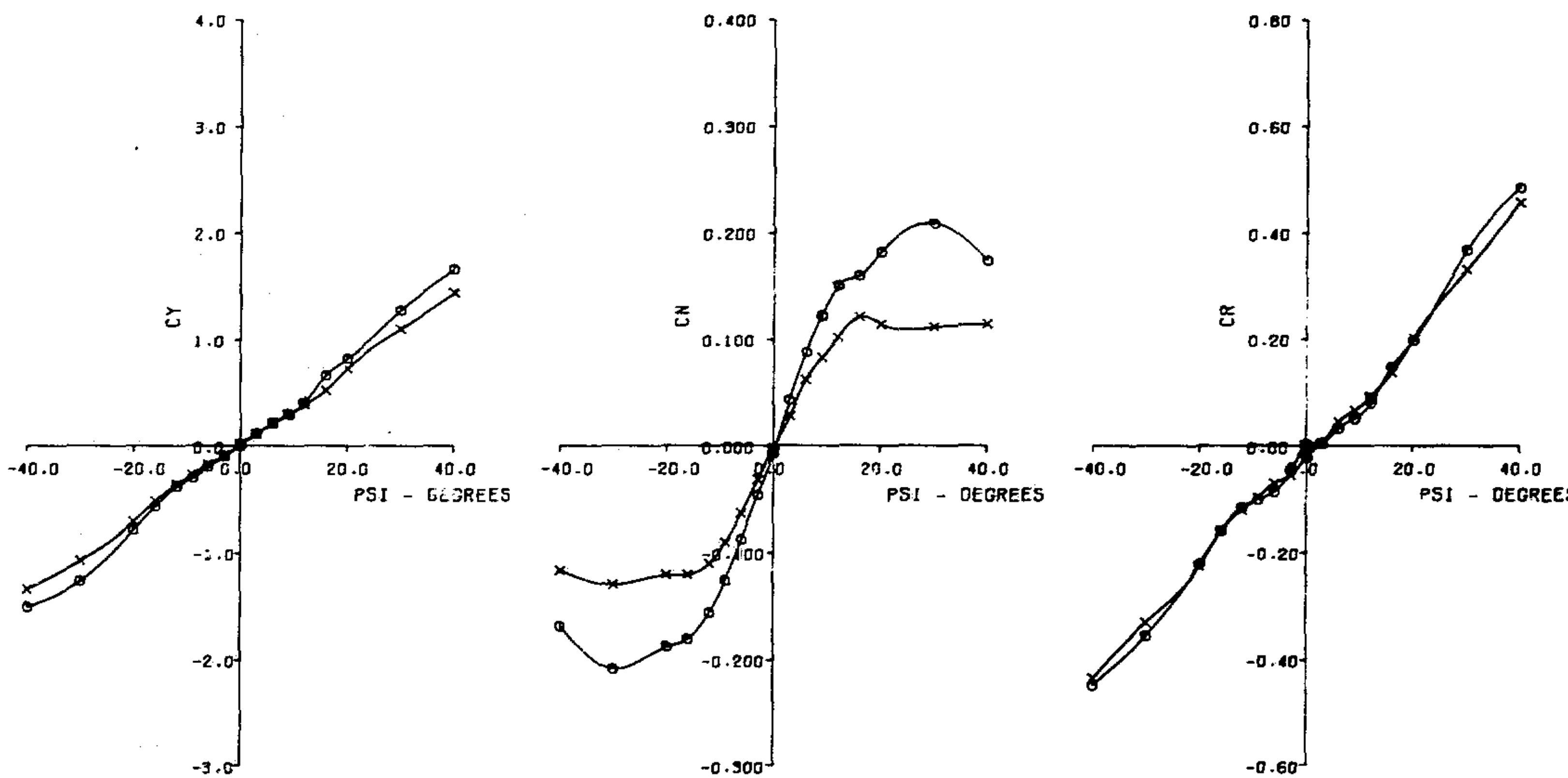

SYM	RUN	CONFIGURATION		Q PSF
o	31	CITI CAR	RADIATOR N.A. . WINDOWS CLOSED.1# PAD	7.94
x	32	CITI CAR	RADIATOR N.A. . WINDOWS OPEN .1# PAD	7.93

CITICAR
LIFT, PITCHING MOMENT, AND DRAG
CHARACTERISTICS

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FIGURE

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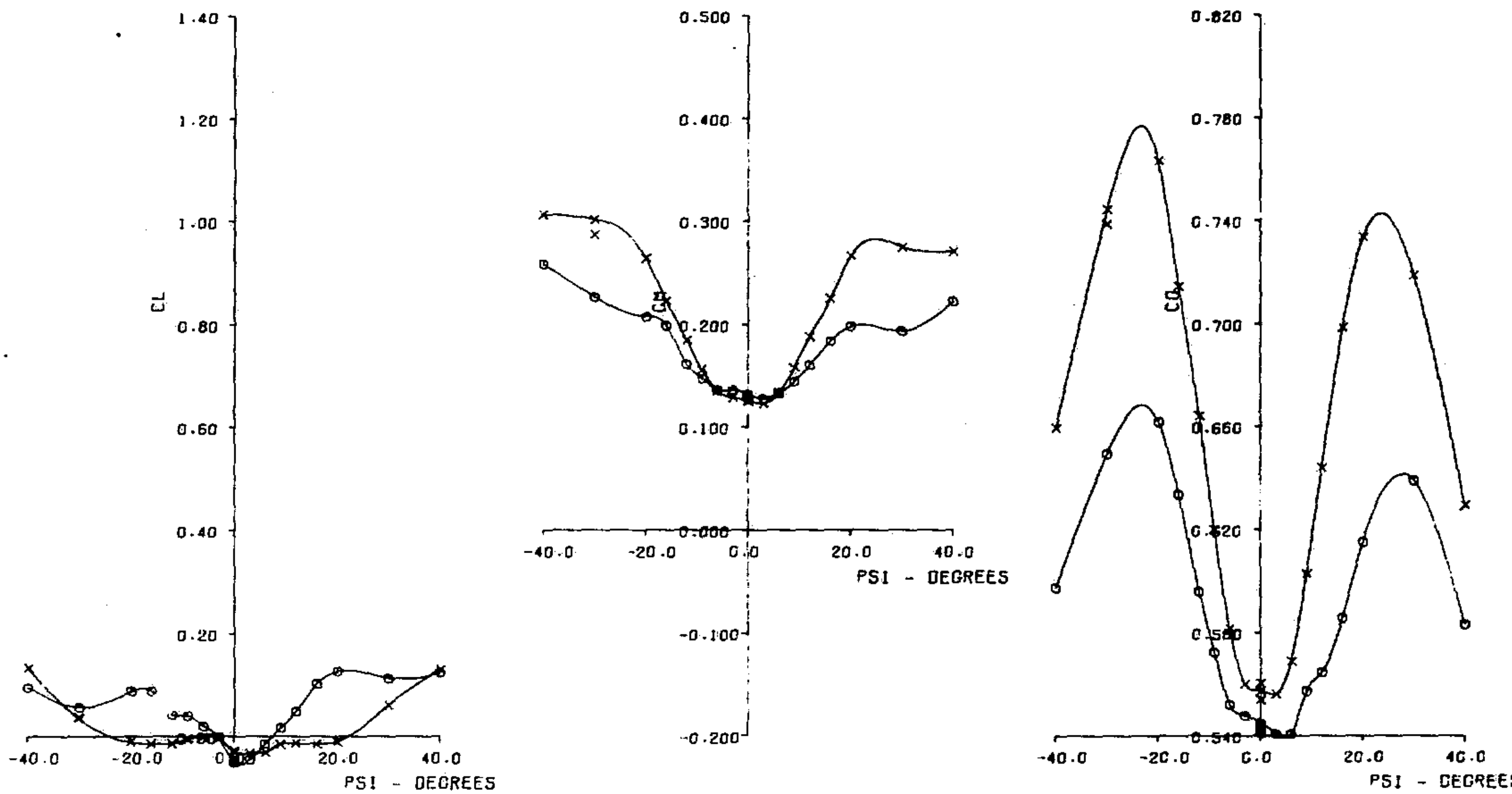

SYM	RUN	CONFIGURATION	Q PSF
⊙	31	CITI CAR RADIATOR N.A. , WINDOWS CLOSED.1° PAD	7.94
×	32	CITI CAR RADIATOR N.A. , WINDOWS OPEN .1° PAD	7.93

CITICAR
SIDEFORCE, YAWING AND ROLLING MOMENT
CHARACTERISTICS

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FIGURE

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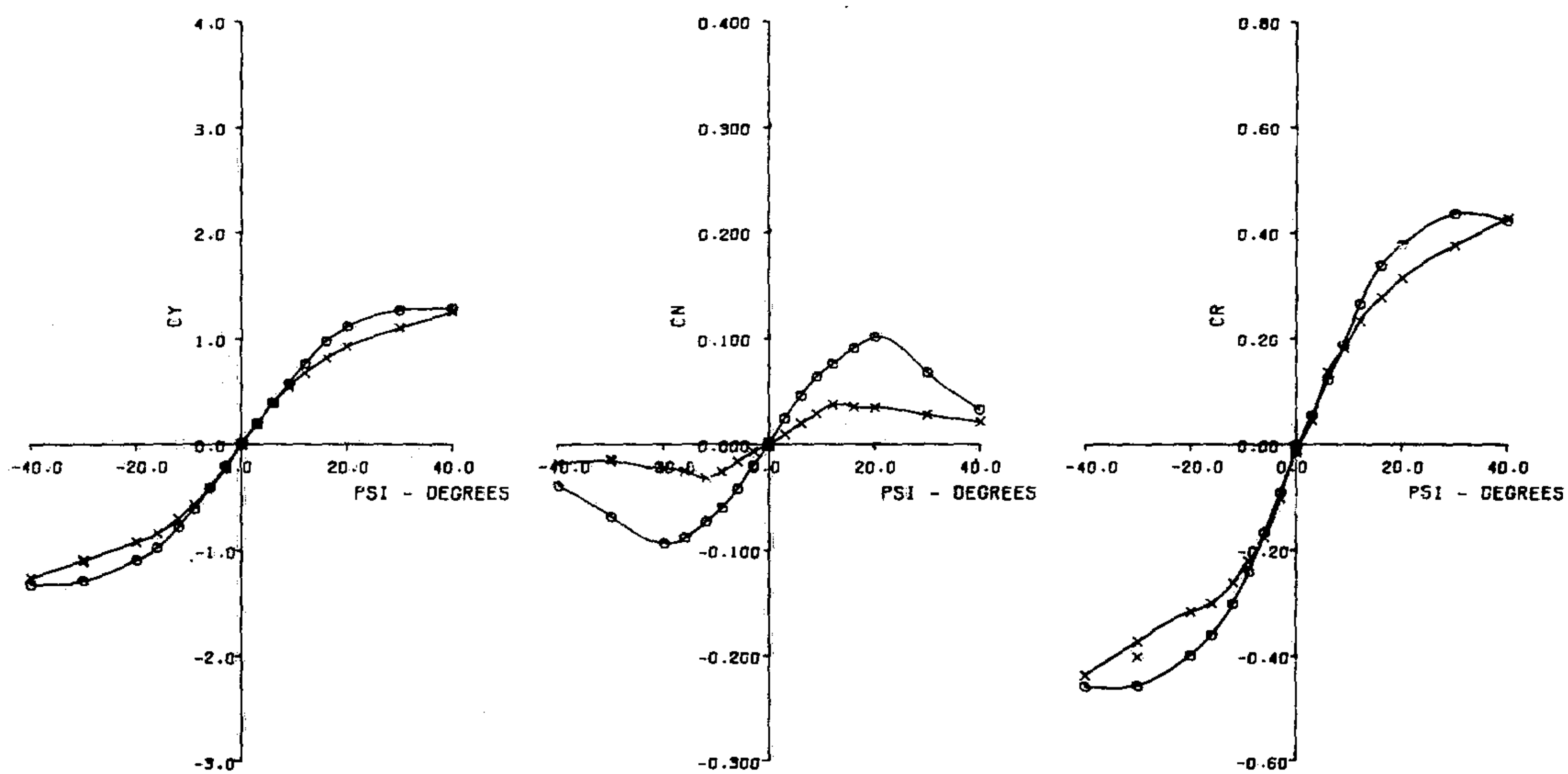

SYM	RUN	CONFIGURATION	Q PSF
o	33	ELCAR RADIATOR N.A. , WINDOWS CLOSED.1* PAD	7.89
x	34	ELCAR RADIATOR N.A. , WINDOWS OPEN .1* PAD	7.96

ELCAR
LIFT. PITCHING MOMENT. AND DRAG CHARACTERISTICS

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FIGURE

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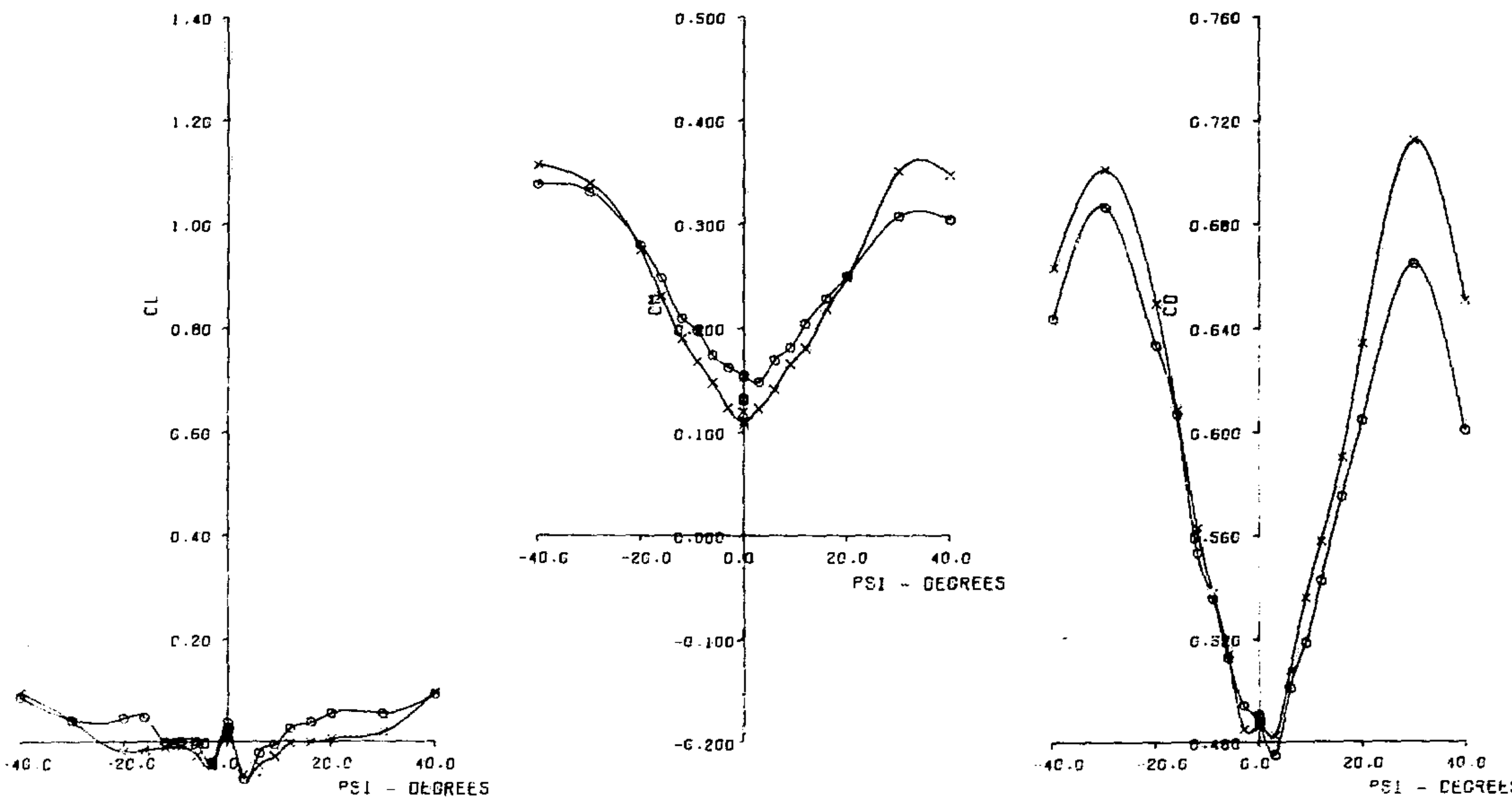

SYM	RUN	CONFIGURATION	Q PSF
o	33	ELCAR RADIATOR N.A. , WINDOWS CLOSED,1* PAD	7.89
x	34	ELCAR RADIATOR N.A. , WINDOWS OPEN ,1* PAD	7.96

ELCAR
SIDEFORCE, YAWING AND ROLLING MOMENT CHARACTERISTICS

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FIGURE

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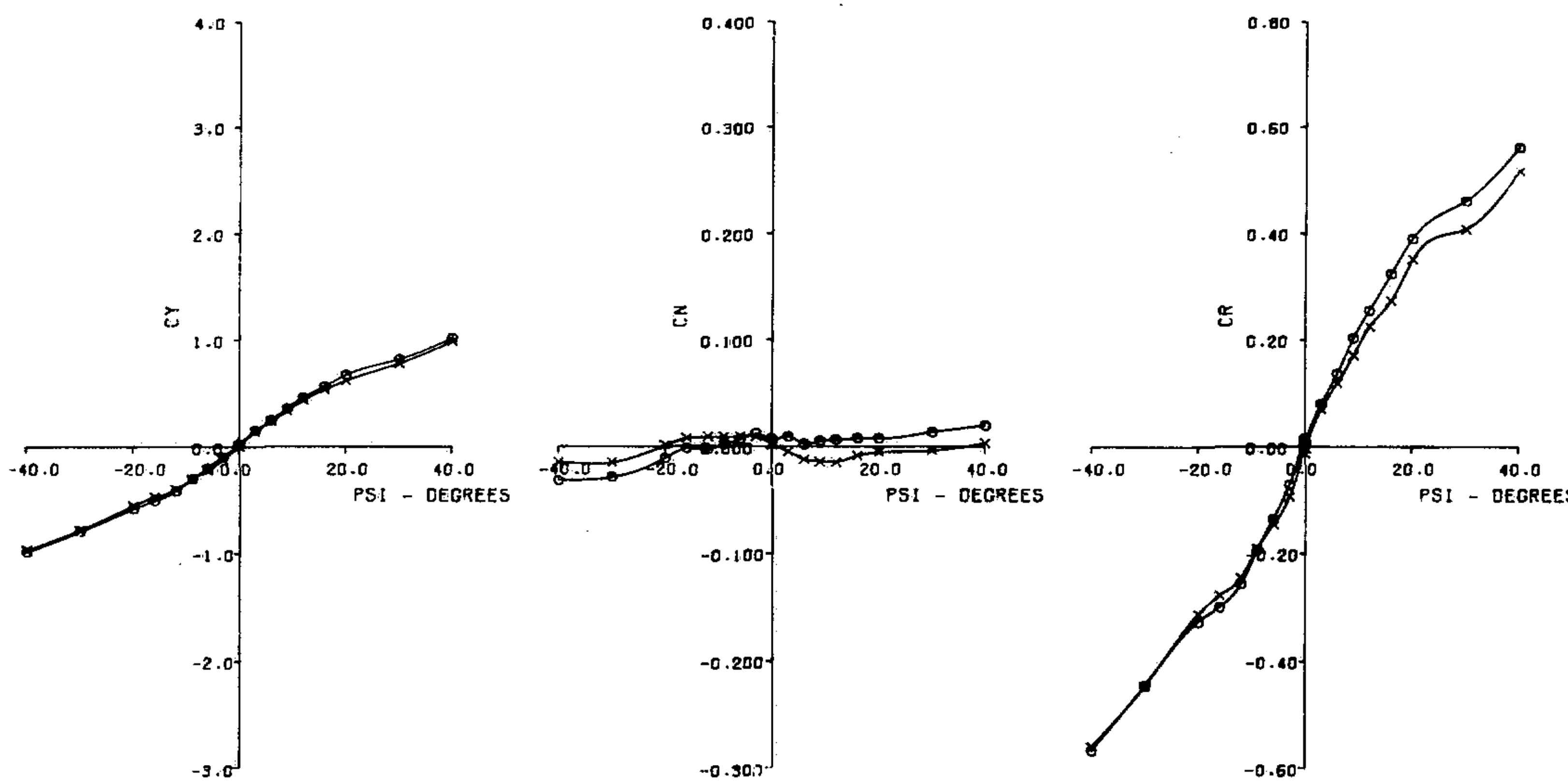

APPENDIX C

EFFECTS OF AMBIENT WINDS ON VEHICLE DRAG

As a vehicle moves along a roadway, it normally operates in a windy environment. Since the resulting wind vector is usually not aligned with the vehicle's longitudinal axis, it is effectively yawed with respect to the flow. Therefore, range predictions that utilize the zero-yaw drag values will inaccurately characterize the aerodynamic contribution and yield optimistic results.

A procedure to accurately determine the effects of ambient winds on vehicle drag has recently been developed.* The approach is to figuratively (in a computer simulation) drive a vehicle over a prescribed velocity-time schedule in the presence of a wind which varies statistically in speed (a speed probability function designated by some annual mean wind speed) and comes with equal probability from any direction. The resultant combination of the vehicle and wind velocity vectors yields an instantaneous yaw angle with respect to the vehicle. If the vehicle's drag-yaw characteristic is known or assumed, the resultant drag may be determined at each instant. Therefore, the energy required to overcome aerodynamic resistance is calculated by integrating the instantaneous aerodynamic power required over the cycle. It is then possible to determine the constant drag coefficient that would have been necessary in order to yield the same result. The ratio of this new effective coefficient, CD_{eff}, to the original zero-yaw drag coefficient, CD_0, is the wind weighting factor, F. F is thus a multiplier to correct the zero-yaw drag coefficient for the effects of ambient winds.

This rigorous procedure was used to generate these factors for a large range of vehicle characteristics, wind conditions, and driving cycles. Analysis of these results yielded many fortuitous relationships leading to simplifying assumptions which are accurate to within about 3%.

The wind-weighting factor, F, was found to be a simple exponential function of the dominant parameter, CD_{max}/CD_0; the yaw angle where CD_{max} occurs is of second order significance and is neglected. F is then, in addition, only a function of the annual mean wind speed and the particular driving cycle or constant speed. The resulting equations for F are given in Tables C-1 and C-2 in metric and English units, respectively. For computer simulator applications, one may either key the wind weighting factor to the choice of driving cycle or instantaneously calculate the effective drag coefficient using the constant speed equation. (In the former case it would be necessary to have all these equations in the program library, and any user-defined nonstandard driving cycle could not be accommodated; the later case, however, often requires major alterations to the program.) Recall that F is the factor by which a

*Dayman, Bain Jr., Realistic Effects of Winds on the Aerodynamic Resistance of Automobiles, SAE Paper No. 780337, Feb. 1978.

zero-yaw drag coefficient, CD_0, must be multiplied in order to yield the effective drag coefficient CD_{eff}. That is,

$$CD_{eff} = F * CD_0$$

W is the annual mean wind speed, which can be chosen by the user with a default value of 12 kph (the average annual mean wind speed in the U.S.). It should be noted that this is not a constant average speed, but rather a statistical average. For instance, an annual mean wind speed of 12 kph has winds of up to 50 kph occurring about 3% of the time and winds less than 12 kph occurring about 70% of the time. CD_{max}/CD_0 is the ratio of the maximum yaw-related drag coefficient (which usually occurs at about 30 degrees) to the drag coefficient at zero-yaw. The user can input this value if he has the information. A default value of 1.25 and 1.45 for front windows closed and open, respectively, represents an average of the data presented in this report.

Table B-1. Wind-Weighting Factor Equations - Metric Units

W = annual mean wind speed in kph

V = vehicle speed in kph

EPA CYCLES

URBAN:

$$F = (1.5 \times 10^{-4} W^2 + 1.5 \times 10^{-2} W) \quad (CD_{max}/CD_0) - 9.3 \times 10^{-3} W + 1.0$$

HIGHWAY:

$$F = (3.6 \times 10^{-4} W^2 + 6.2 \times 10^{-3} W) \quad (CD_{max}/CD_0) - 9.3 \times 10^{-3} W + 1.0$$

SAE ELECTRIC CYCLES (J227a)

B: $$F = (3.5 \times 10^{-4} W^2 + 3.6 \times 10^{-2} W) \quad (CD_{max}/CD_0) - 2.2 \times 10^{-2} W + 1.0$$

C: $$F = (4.6 \times 10^{-4} W^2 + 1.4 \times 10^{-2} W) \quad (CD_{max}/CD_0) - 1.1 \times 10^{-2} W + 1.0$$

D: $$F = (4.6 \times 10^{-4} W^2 + 4.9 \times 10^{-3} W) \quad (CD_{max}/CD_0) - 1.0 \times 10^{-2} W + 1.0$$

CONSTANT SPEED

$$F = \left[0.98(W/V)^2 + 0.63(W/V)\right] \quad (CD_{max}/CD_0) - 0.40(W/V) + 1.0$$

Constraints:*

For $(W/V) < 0.09$ $\quad F = 1.0$

For $(W/V) > 1.0$ $\quad (W/V) = 1.0$

*These constraints may be necessary if this equation is applied to the quasi-steady instantaneous vehicle speeds in a computer simulation (i.e., the function goes to infinity at V = 0). In a physical sense, however, the equation is entirely proper without these boundary conditions.

Table B-2. Wind-Weighting Factor Equations - English Units

W - annual mean wind speed in mph

V = vehicle speed in mph

EPA CYCLES

URBAN:

$$F = (3.9 \times 10^{-4} W^2 + 2.4 \times 10^{-2} W) \quad (CD_{max}/CD_0) - 1.5 \times 10^{-2} W + 1.0$$

HIGHWAY:

$$F = (9.3 \times 10^{-4} W^2 + 10^{-2} W) \quad (CD_{max}/CD_0) - 1.5 \times 10^{-2} W + 1.0$$

SAE ELECTRIC CYCLES (J227a)

B: $$F = (9 \times 10^{-4} W^2 + 5.8 \times 10^{-2} W) \quad (CD_{max}/CD_0) - 3.6 \times 10^{-2} W + 1.0$$

C: $$F = (1.2 \times 10^{-3} W^2 + 2.3 \times 10^{-2} W) \quad (CD_{max}/CD_0) - 1.7 \times 10^{-2} W + 1.0$$

D: $$F = (1.2 \times 10^{-3} W^2 + 7.9 \times 10^{-3} W) \quad (CD_{max}/CD_0) - 1.6 \times 10^{-2} W + 1.0$$

CONSTANT SPEED

$$F = 0.98(W/V)^2 + 0.63(W/V) \quad (CD_{max}/CD_0) - 0.40(W/V) + 1.0$$

Constraints:

For $(W/V) < 0.09$ $F = 1.0$

For $(W/V) > 1.0$ $(W/V) = 1.0$