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AN INVESTIGATION OF DRAG REDUCTION FOR A BOX-SHAPED VEHICLE WITH VARIOUS MODIFICATIONS

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LIST OF SYMBOLS

A	Projected frontal area (less wheels) on a plane perpendicular to the centerline of vehicle, .0396 sq m (.4278 sq ft)
C_D	Coefficient of drag, D/qA
C_L	Coefficient of lift, L/qA
C_M	Coefficient of pitching moment, PM/qAc
C_Y	Coefficient of side force, SF/qA
C_ℓ	Coefficient of rolling moment, RM/qAc
C_N	Coefficient of yawing moment, YM/qAc
C_{D_X}	Coefficient of drag, configuration X
C_{P_b}	Coefficient of base pressure, $(P_b - P_A)/q$
c	Reference length (vehicle length for C_M) (vehicle width for C_ℓ, C_N)
D	Drag (vehicle axis)
D_e	Equivalent diameter, $\sqrt{4A/\pi}$
L	Lift (vehicle axis)
P	Power
P_A	Atmospheric pressure
P_b	Base pressure
PM	Pitching moment (vehicle axis)
q	True dynamic pressure in wind tunnel test section, $\frac{1}{2}\rho V^2$
RM	Rolling moment (vehicle axis)
R_N	Reynolds number (based on equivalent diameter), $\frac{\rho V D_e}{\mu}$
SF	Side force (vehicle axis)
V	Relative wind speed = Wind tunnel airspeed

LIST OF SYMBOLS (cont'd)

V_1	Vehicle speed
V_2	Side wind component
W	True wind speed
YM	Yawing moment (vehicle axis)
β	Wind angle relative to vehicle path
ρ	Air density
μ	Air viscosity
ψ	Yaw angle = Relative wind angle

note: the term "full-scale" (with quotation marks) as used herein refers to a vehicle scaled-up from the model by a factor of 10 which would result in the length and width dimensions of the test vehicle reported in references 1 and 2. The reference area of such a vehicle would be 3.96 sq. m. {(80in. x 77in.) $\div$ 144 = 42.78 sq. ft.} The values of power required to overcome aerodynamic drag, calculated fuel consumption and calculated fuel savings presented here-in pages 4, 6, 20, 21, 22, 23, 32, 33 and APPENDIX, are all based on a vehicle having the above noted dimensions. The power required to overcome aerodynamic drag, fuel consumption and potential fuel savings for standard sized motor-homes will be larger by the ratio of reference areas (for many, larger by 30% to 35%).

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The advice and comments of Mr. Edwin Saltzman, Dryden Flight Research Center, are gratefully acknowledged. The wind tunnel testing and data reduction were conducted by the following students in the Department of Aerospace Engineering, University of Kansas:

Steven Ericson, Undergraduate student

Charles Svoboda, Undergraduate student

1.0 INTRODUCTION

Recreation vehicles such as vans and motor homes generally have been constructed along box-shaped exterior lines. This shape is advantageous in some respects because it has a large usable volume and is easy to manufacture. Its obvious disadvantage is the high aerodynamic drag.

A basic box-shaped vehicle with several modifications was tested by Saltzman and Meyer[1,2] at the NASA Dryden Flight Research Center. Wind tunnel tests of one-tenth scale models of the NASA configurations, and several modifications of the NASA configurations, were tested by Muirhead.[3]

More recent wind tunnel tests have been conducted on box-shaped vehicles somewhat similar to the earlier one-tenth scale models. The baseline model for these tests was the original one-tenth scale model[3] with an additional height of 3.3 cm (1.3") on the top of the vehicle. Three modifications were made to the baseline model to determine the effect on drag of:

a. Built-in rounded corners on the front of the vehicle.

b. Flow-vanes added to the baseline model which otherwise had square front corners. The flow-vanes were added to the front of the vehicle (two different flow-vane arcs: 67° and 90°) (Reference 4).

c. Relative wind angle, yaw angle, on the relative efficiency of the rounded corners as compared to the flow-vane concept.

2.0 APPARATUS AND PROCEDURES

2.1 Models

The hypothetical "full-scale" vehicle would be the vehicle in Figure 2.1.1 (Reference 1) with the addition of 13" to the top of the vehicle.

The baseline one-tenth scale wind tunnel model is shown in Figure 2.1.2. The present model is a derivative of the model used for the Reference 3 experiment except that the box height has been increased by a factor of 1.2. The dimensions of the baseline wind-tunnel model are shown in Figure 2.1.3. The bottom of the model was smooth, identical to Configuration No. 1 of Reference 3. The model frame was constructed for the wind-tunnel tests from aluminum. Front, rear and top corner blocks which determine whether the corners are "sharp," i.e., square, or rounded, were constructed from maple wood.[3] The flow-vanes, Reference 4, were constructed from brass as shown in Figure 2.1.4. The radius of the built-in rounded corners and the flow vanes was 4.1 cm (1.6"). Photographs of model configurations 2, 3 and 4 are shown in Figures 2.1.5 through 2.1.7. The several configurations were assembled and tested in accordance with Figure 2.1.8.

2.2 Mounting

The wind-tunnel mounting system for the models, Figure 2.2.1, was the same system that had been used on previous tests.[3] The ground board enclosed the balance mounting strut and mounting plate. The model was held to the mounting plate by four adjustable rods attached to the vehicle frame and running through the wheels. The model was adjusted vertically on the rods to position the model to the correct height above the ground board. The bottom of the wheels were sanded off so that they did not touch the ground board during tests. The ground board contained two circular slots to allow the model to be rotated thirty degrees in each direction. During the tests the slots were covered except for a small clearance around each mounting rod.

The horizontal pressure gradient on the ground board was zero. The board was tufted to check for flow separation. The front of the ground board was rounded slightly to eliminate a small flow separation at the leading edge.

2.3 Tests

The tests were conducted in the University of Kansas .91 by 1.29 meter wind-tunnel at Reynolds numbers of 4.5×10^5 to 8.2×10^5 based upon the equivalent diameter of the vehicles or 10.1×10^5 to 18.4×10^5 based upon the length of the basic test model, Configuration 1. The Reynolds number was controlled by adjusting the wind-tunnel airspeed from 36.5 to 66.5 meters per second (81.7 to 148.8 miles per hour). Tests were made at yaw (relative wind) angles of 0°, 5°, 10°, 20° and 30° on the configurations at four different Reynolds numbers. Force and moment data were obtained from a six component strain-gaged balance. Base pressures were measured by a pressure transducer. The orifice was located at the center of the base region.

Wind-tunnel test data were obtained through a newly installed analog/digital data system controlled by a Hewlett Packard 9825 calculator.

3.0 RESULTS AND DISCUSSION

3.1 Drag

Drag coefficients were computed from the force acting along the model axis. The reference area used was the projected frontal area (A) for all configurations. These coefficients were plotted as a function of Reynolds number at each yaw angle on workplots, which are not included in this report. Subsequently, drag coefficient values were extracted from these plots at a Reynolds number of 8×10^5 (based upon equivalent diameter). These values are shown in Table I. Figure 3.1.1 shows the variation of the drag coefficient with yaw (relative wind) angle at this Reynolds number for Configuration 1. Figure 3.1.2 shows a comparision of the drag coefficients of the four configurations tested at various yaw angles for a Reynolds number of 8×10^5. These drag coefficients were normalized by dividing each drag coefficient by the drag coefficient for Configuration 1. Table II presents drag reductions resulting from the various modifications, in percent relative to the baseline model, Configuration 1.

Table III compares the data obtained from the present wind tunnel tests with data obtained by Saltzman and Meyer[1] and Muirhead[3]. The built-in rounded front corners produced a decrease of from 58.6 to 62.2 percent in the three similar tests.

The drag data included herein and other data obtained during the tests indicate the following:

1. The effect of the Reynolds number was small.
2. The built-in rounded front corners on the forward end of the box-shaped vehicle produced a decrease in drag of 62.2% at 0° wind angle and an average decrease in drag of 61.1% over a range of relative wind angles from 0° to 20°.
3. The flow-vanes with 67° arc produced a 61.7% decrease in drag at 0° wind angle. Over the 0° to 20° relative wind angle range the average decrease in drag was 48.8%
4. The flow-vanes with a 90° arc produced a 62.9% decrease in drag at 0° wind angle. Over the 0° to 20° relative wind angle range the average decrease in drag was 57.3%.

The base pressure data variation with relative wind angle is shown in Figure 3.1.3 for Configuration 1. Table IV contains the base pressure data for all configurations. Figure 3.1.4 provides a comparison of the base pressure coefficients. The improved flow around the front of the vehicle provided by the rounded corners and the flow-vanes made the base pressure significantly more negative at small relative wind angles and slightly more negative at large relative wind angles.

The power required to overcome the aerodynamic drag for a "full-scale" vehicle, Configuration 1, at 88.5 kilometers per hour (55 mph) ground speed was calculated using the wind speeds of 0, 15.3 and 30.6 kilometers per hour (0, 9.5 and 19.0 mph). Wind angles of 0° through 180° relative to the vehicle path were used, Figure 3.1.5. The corresponding values for Configurations 2, 3, and 4 are given in Figures 3.1.6 through 3.1.8. Table V presents the power to overcome aerodynamic drag required for all configurations. These data represent: (1) the no-wind condition, (2) a 15.3 km per hour (9.5 mph) wind and (3) a 30.6 km per hour (19.0 mph) wind each averaged over the entire range of directions from 0° to 180°. For a standard full-scale motor-home the power required to overcome aerodynamic drag would be about 30% to 35% greater, see note on page iv.

The calculated values of average power required to overcome aerodynamic drag has special significance for the lower of the two wind speeds, i.e., 15.3, km per hour (9.5 mph). This is because this wind speed closely approximates the average annual winds for the 48 contiguous United States. Thus, fuel consumption values calculated from this wind speed will include the approximate wind effects over an extended period of time, such as a year or more.

Table VI contains the values of average fuel consumption per hour to overcome the aerodynamic drag and the resulting fuel costs in the presence of the aforementioned average annual winds. A diesel brake specific fuel consumption of 2.129×10^{-4} kg of fuel per watt hour (.35 pounds of fuel per horsepower hour) has been used. These values of brake specific fuel consumption should be multiplied by 1.46 ft if a gasoline engine were to be used. Fuel costs were assumed to be 26.4 cents per liter ($1.00 per gallon). For a diesel powered vehicle, Configuration 2 (built-in rounded front corners) provides a saving of about 6.0 liters per hour of driving (1.6 gallons per hour) over the baseline configuration for national average annual winds and for a ground speed of 88.6 km/hr (55 mph). The corresponding savings for the flow-vanes were 5.5 liters per hour (1.5 gallons perhour) for the 67 degree arc flow-vane and about 6.0 liters per hour (1.6 gallons per hour) for the 90 degree arc flow-vane.

If a gasoline power plant is used the volumetric fuel consumption and savings are larger than for the diesel. Taking into account the brake specific fuel consumption for gasoline which is larger by a factor of about 1.46 and the fuel density which is lower by a factor of 0.85, the corresponding volumetric savings for a gasoline powered vehicle are approximately 1.7 times larger than those listed for diesel fuel. As mentioned on page iv, the fuel consumption values and the fuel savings would be another 30% to 35% greater for a standard size motor home.

3.2 Side Force

The side force coefficients were computed from the forces acting on the wind tunnel model perpendicular to the model axis. The reference area used was the projected frontal area (A). The variation of side force with yaw for Configuration 1 is shown in Figure 3.2.1 for a Reynolds number of 8×10^5. The side force coefficients for a Reynolds number of 8×10^5, corrected for wind tunnel flow angularity error, are contained in Table VII. A comparison of the side force coefficients of the various configurations is contained in Figure 3.2.2. The built-in front rounded corners and the flow-vanes increased the side force coefficient over Configuration 1. Rounding the front corners produced similar results for the experiments described in Reference 3.

3.3 Lift

The variation of the lift coefficient with yaw angle for Configuration 1 is shown in Figure 3.3.1. The reference area used was the projected frontal area (A). The lift coefficients of all configurations for a $R_N = 8 \times 10^5$ are given in Table VIII.

3.4 Moments

The pitching, rolling, and yawing moment coefficients of Configuration 1 about a point on the center line of the vehicle 25.4 cm (10.0") from the front of the vehicle and 5.7 cm (2.25") above the ground plane are shown in Figures 3.4.1, 3.4.2, and 3.4.3. The reference area used was the projected frontal area (A); the reference length (c) for the pitching moment was the vehicle length; the reference length (c) for the rolling and yawing moments was the vehicle width. The pitching, rolling and yawing moment coefficients of all configurations are given in Tables IX, X, and XI for a $R_N = 8 \times 10^5$.

The rolling and yawing moment coefficients for all configurations were corrected for flow angularity error.

4.0 CONCLUSIONS

The built-in front rounded corners and the add-on flow-vanes were very effective in improving the flow over the forward part of the vehicle. For a diesel powered vehicle slightly larger than a family van the built-in front rounded corners provided a calculated fuel saving over the baseline vehicle of about 6.0 liters per hour (1.6 gallons per hour) at a driving speed of 88.6 km/hr (55 mph) in national average winds. The corresponding savings for front mounted flow-vanes were about 5.5 liters per hour (1.5 gallons per hour) for the 67° arc flow-vane and 6.0 liters per hour (1.6 gallons per hour) for the 90° arc flow-vane. For a gasoline powered vehicle the corresponding volumetric savings would be increased by a factor of about 1.7.

The fuel savings for a standard size motor home would be greater than for the above noted diesel or gasoline powered vehicles by from 30% to 35% because of the larger frontal area. Thus projected fuel savings for a standard size motor home powered by gasoline can approach 12.5 to 13.5 liter (3.3 to 3.6 gallons) for each hour of driving at highway speeds.

5.0 REFERENCES

1. Saltzman, Edwin J. and Robert P. Meyer, Jr. "Drag Reduction Obtained by Rounding Vertical Corners on a Box-Shaped Ground Vehicle." NASA TM X-56023, March 1974.

2. Saltzman, Edwin J., Robert P. Meyer, Jr. and David P. Lu. "Drag Reduction Obtained by Modifying a Box-shaped Ground Vehicle." NASA TM X-56027, October 1974.

3. Muirhead, V. U. "An Investigation of Drag Reduction on Box-Shaped Ground Vehicles," KU-FRL 180, July 1976.

4. Sheridan, A. E. and Grier, S. J. "Drag Reduction Obtained by Modifying a Standard Truck," NASA TM 72 846, February 1978.

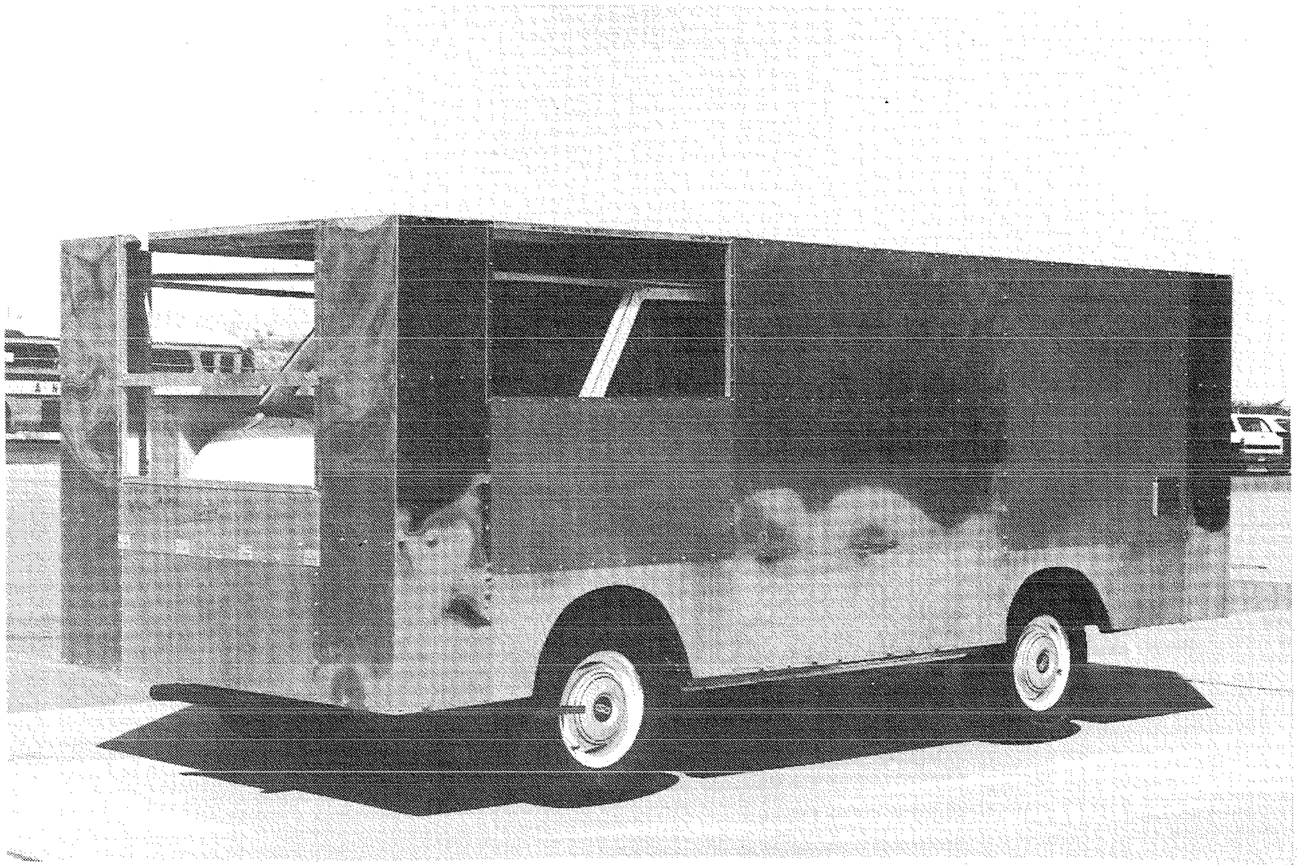


Figure 2.1.1 Full-scale baseline vehicle, except for height (Reference 1)

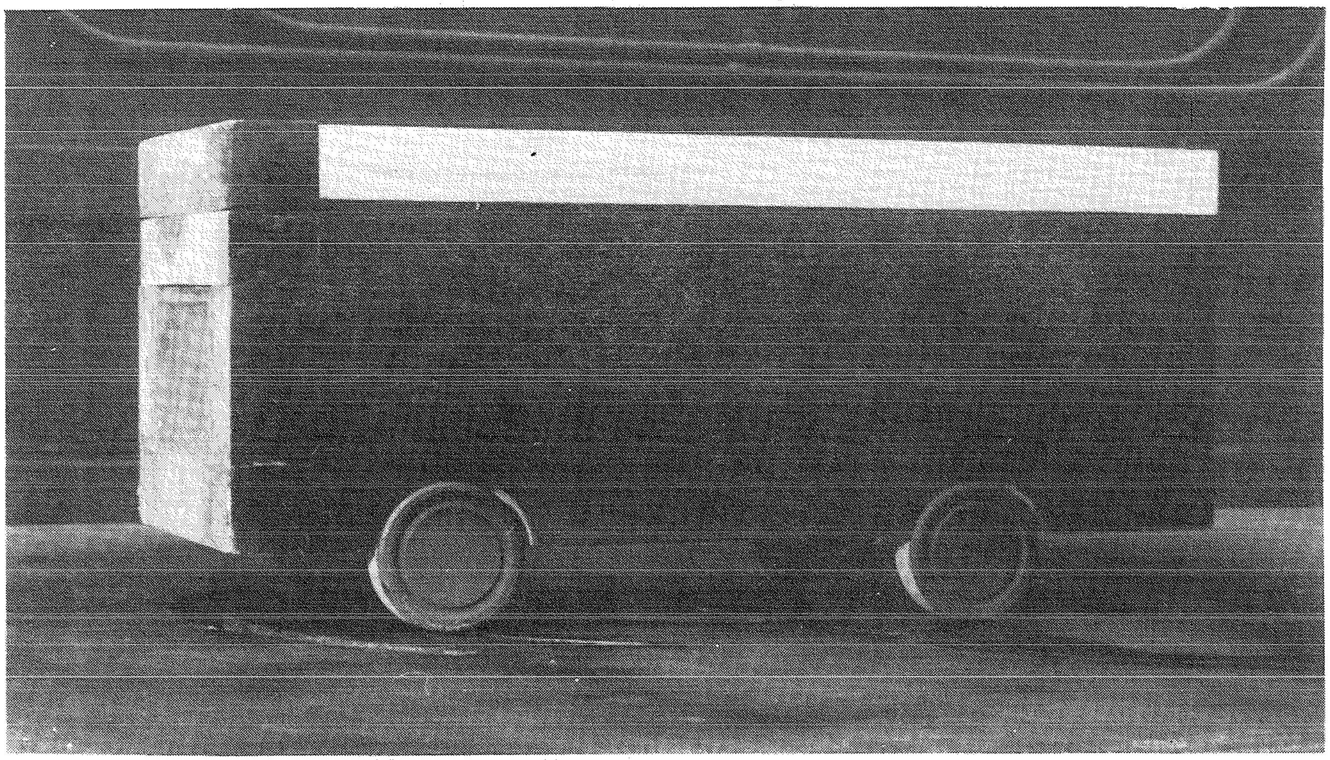


Figure 2.1.2 Baseline wind tunnel model having all square corners, configuration no. 1.

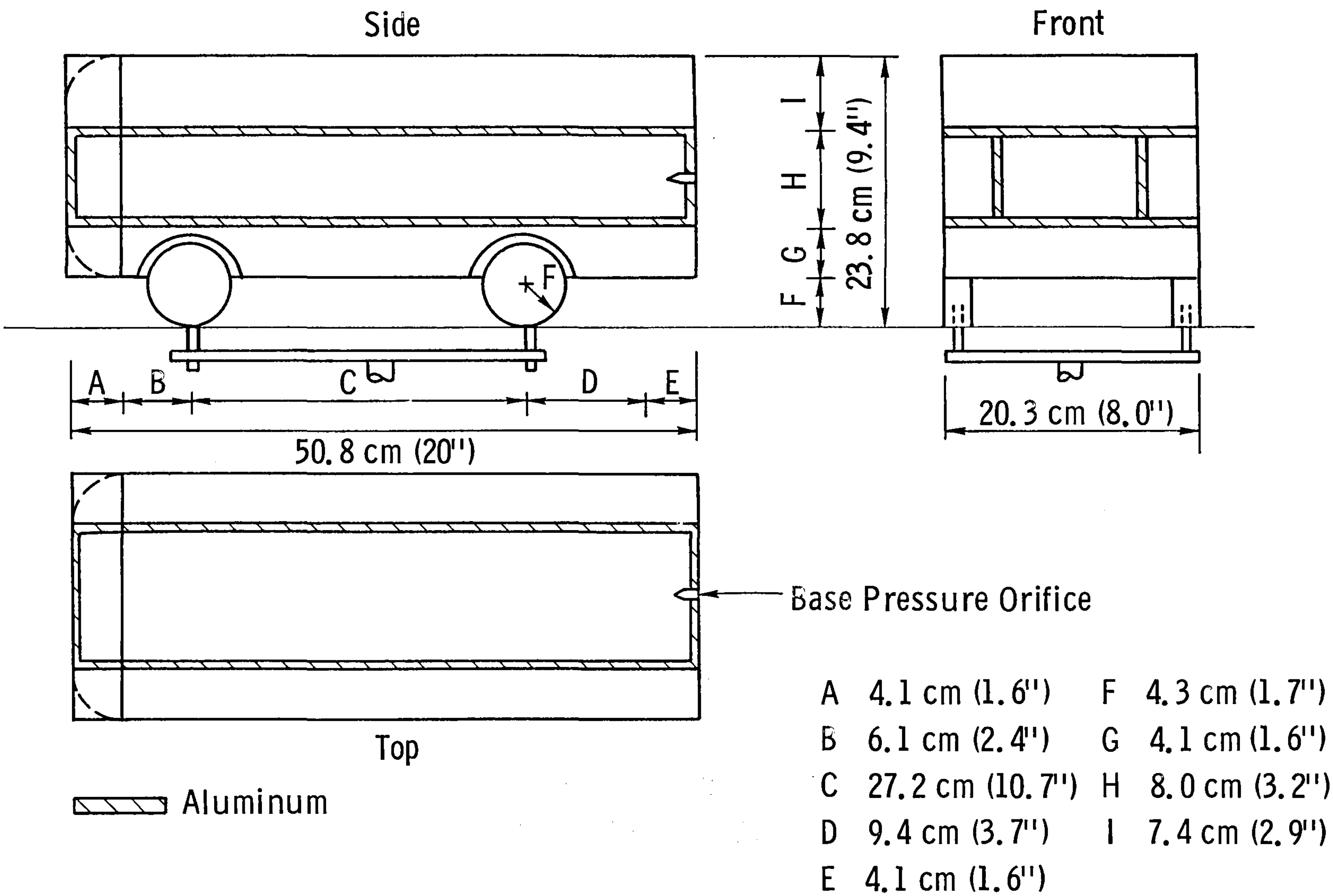


Figure 2.1.3 Top, front and side views of baseline wind tunnel model

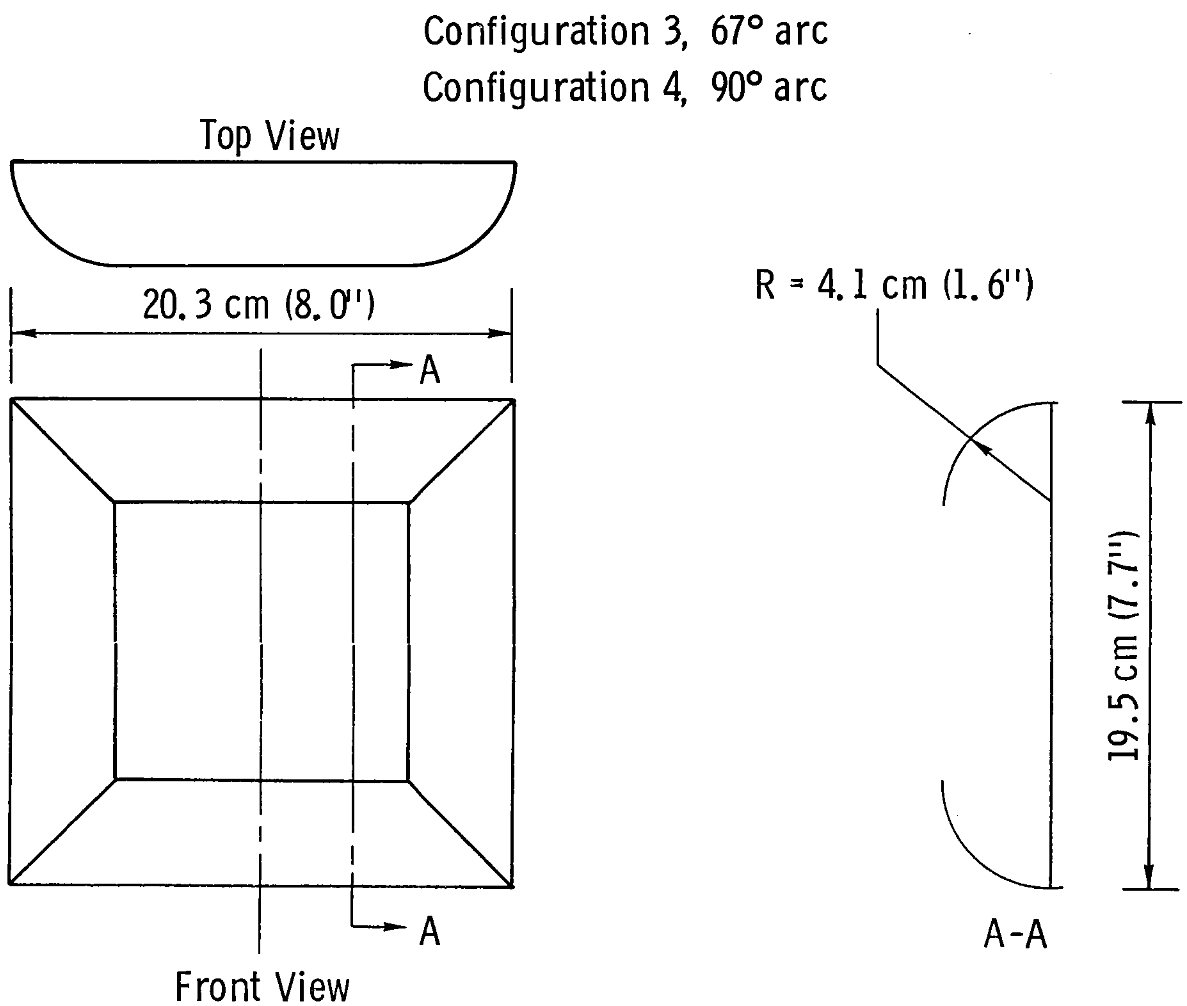


Figure 2.1.4 Flow-vane concept (NASA TM-72846), Reference 4

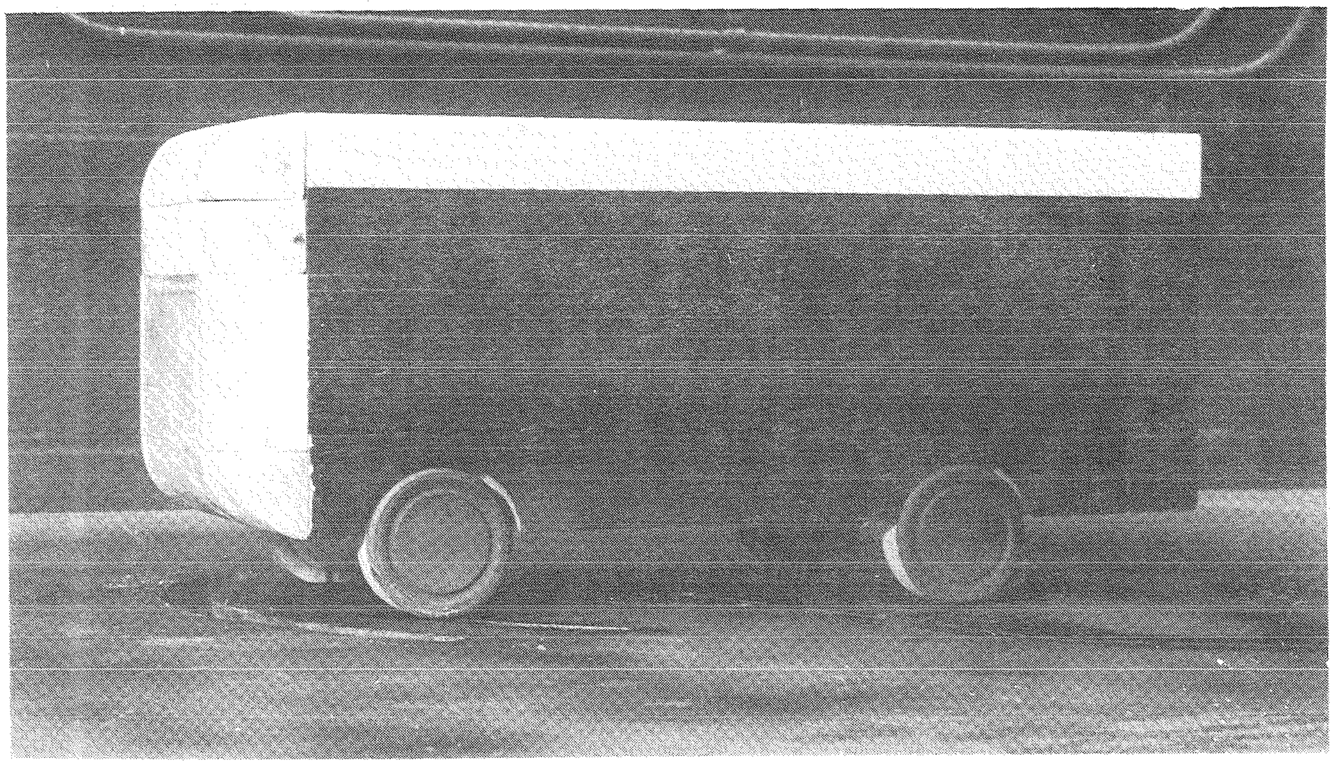


Figure 2.1.5 Model configuration 2 with built-in rounded front corners

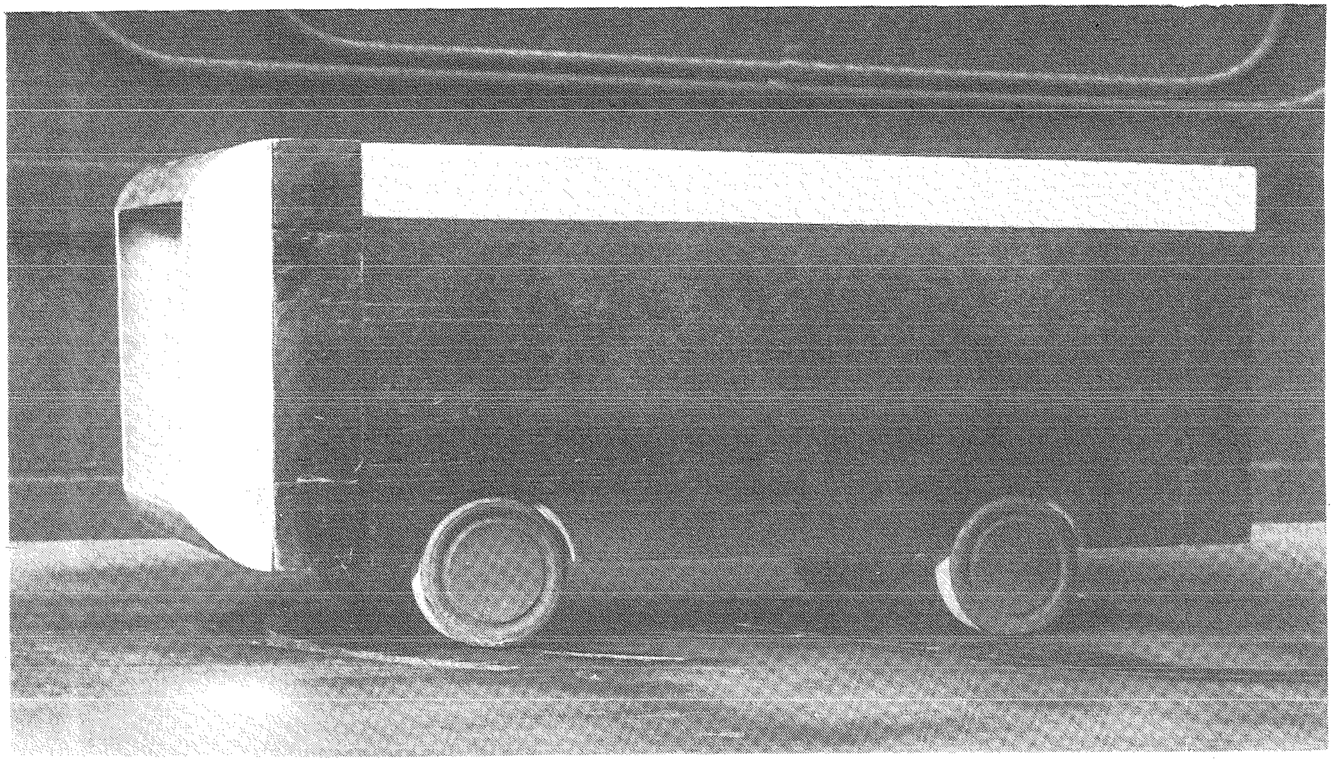


Figure 2.1.6 Model configuration 3 with flow-vanes (67° arc)

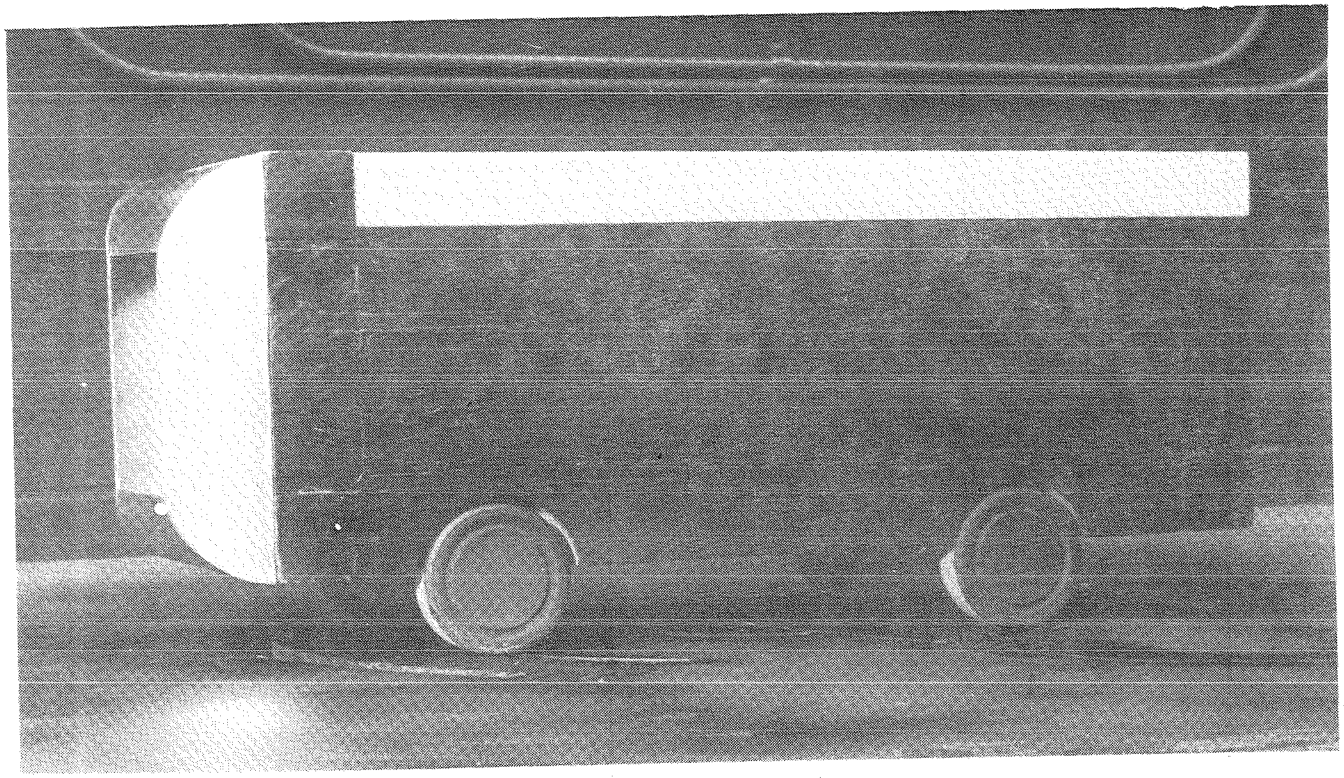
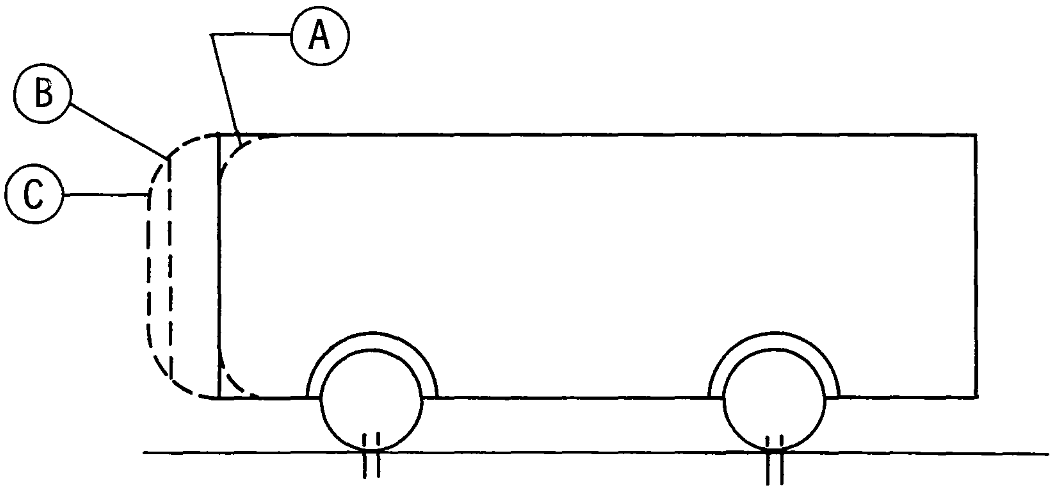


Figure 2.1.7 Model configuration 4 with flow-vanes (90° arc)



Configuration Number		Modifications
1		None; Square Box
2	A	Build-in Rounded Vertical and Horizontal Front Corners
3	B	Flow-Vane Concept (67°)
4	C	Flow-Vane Concept (90°)

Figure 2.1.8 Model configuration chart

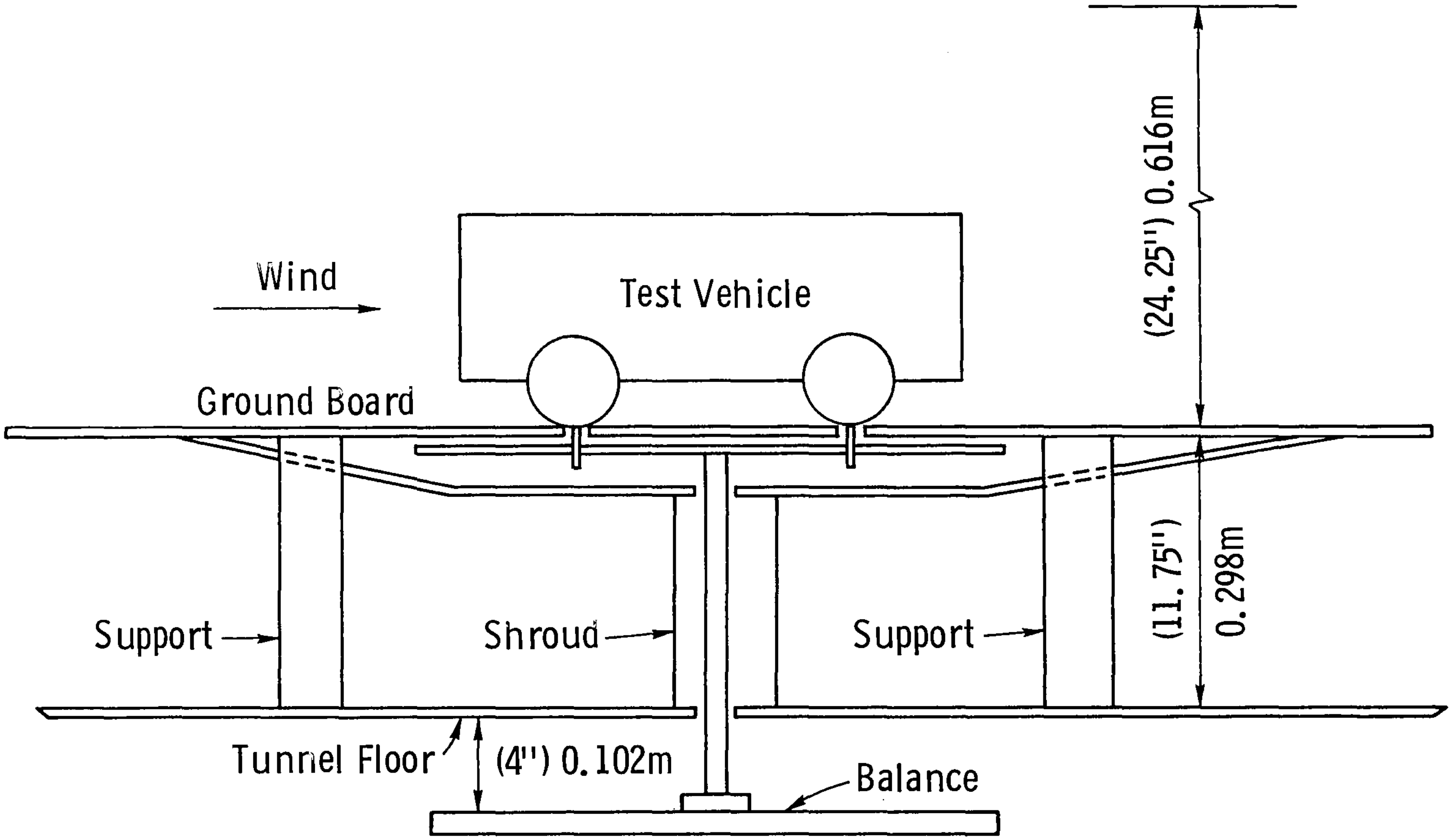


Figure 2.2.1 Wind tunnel mount

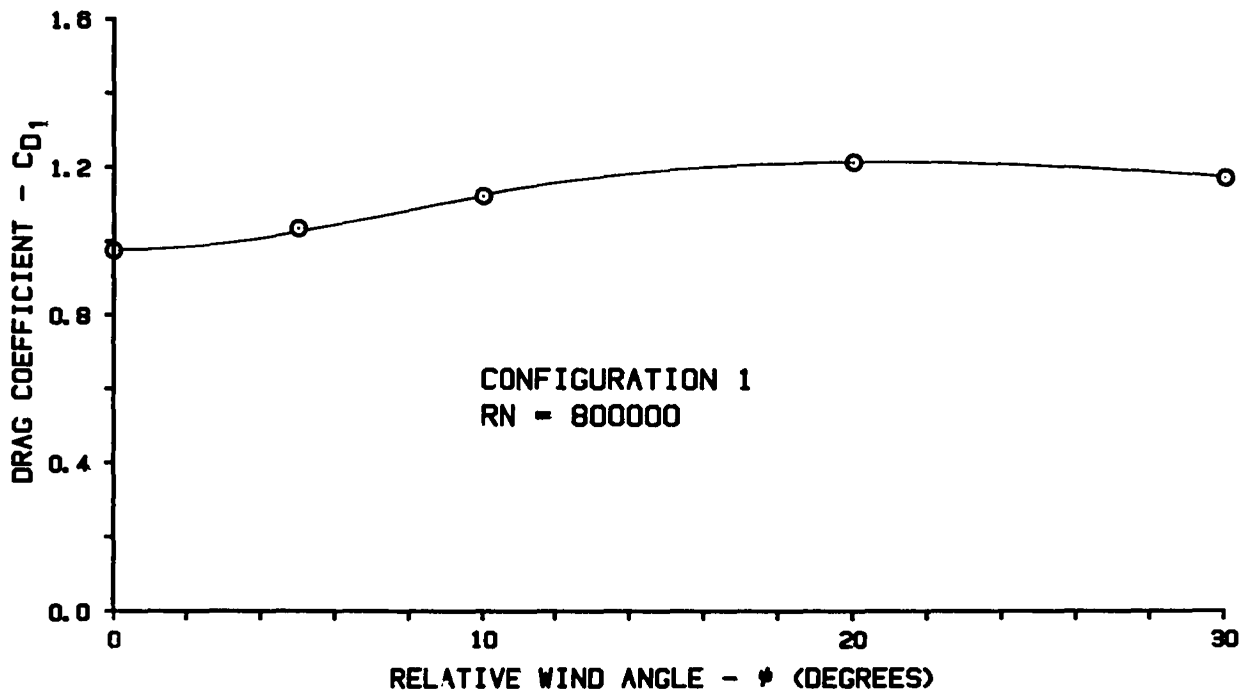


FIGURE 3.1.1 EFFECT OF RELATIVE WIND ANGLE ON DRAG COEFFICIENT C_{D_1}

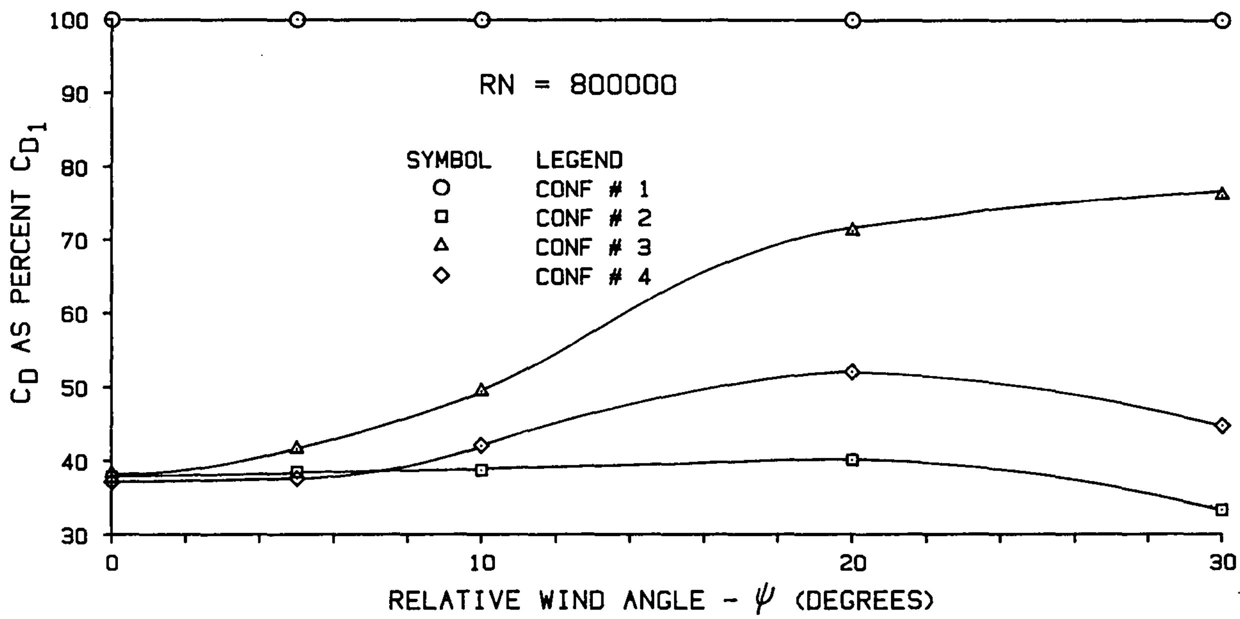


FIGURE 3.1.2 COMPARISON OF DRAG COEFFICIENTS, CONFIGURATIONS 1, 2, 3, 4

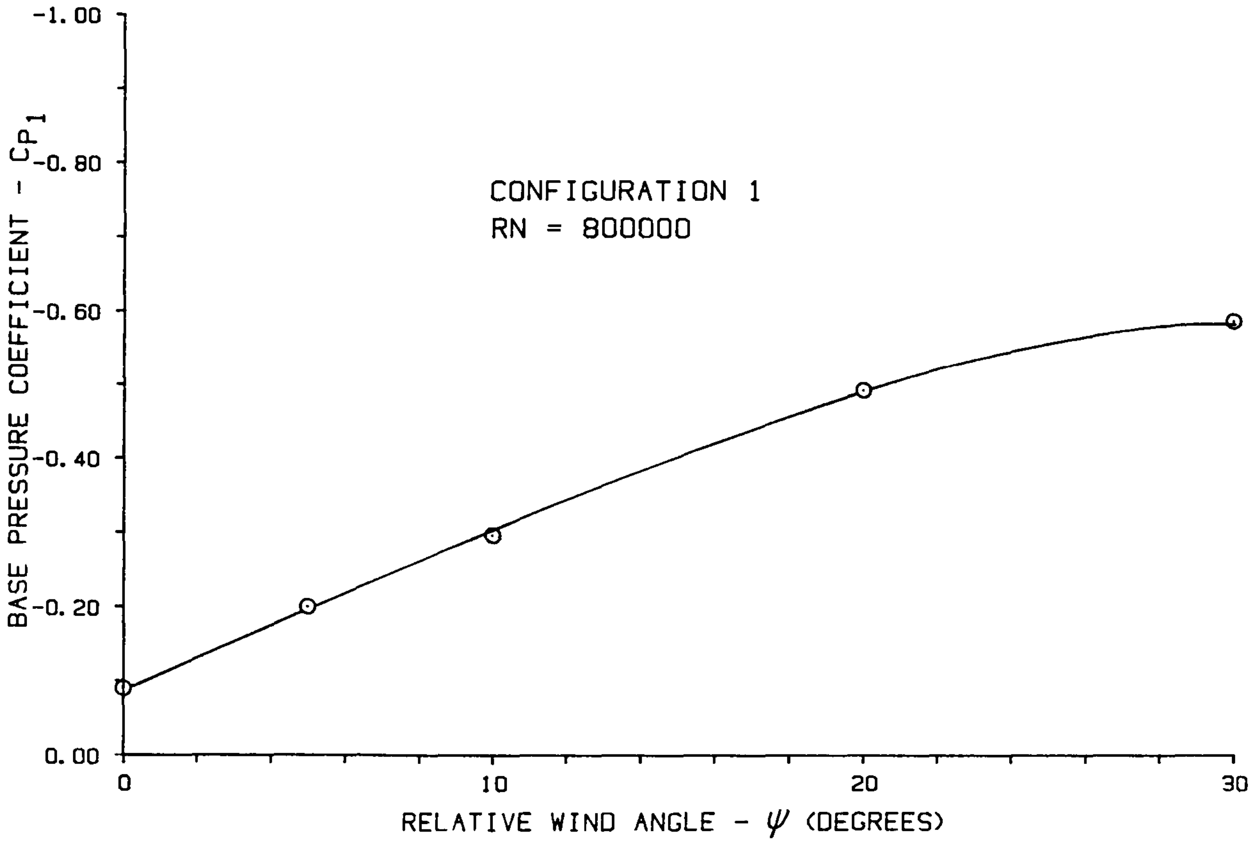


FIGURE 3.1.3 EFFECT OF RELATIVE WIND ANGLE ON BASE PRESSURE COEFFICIENT C_{P_1}

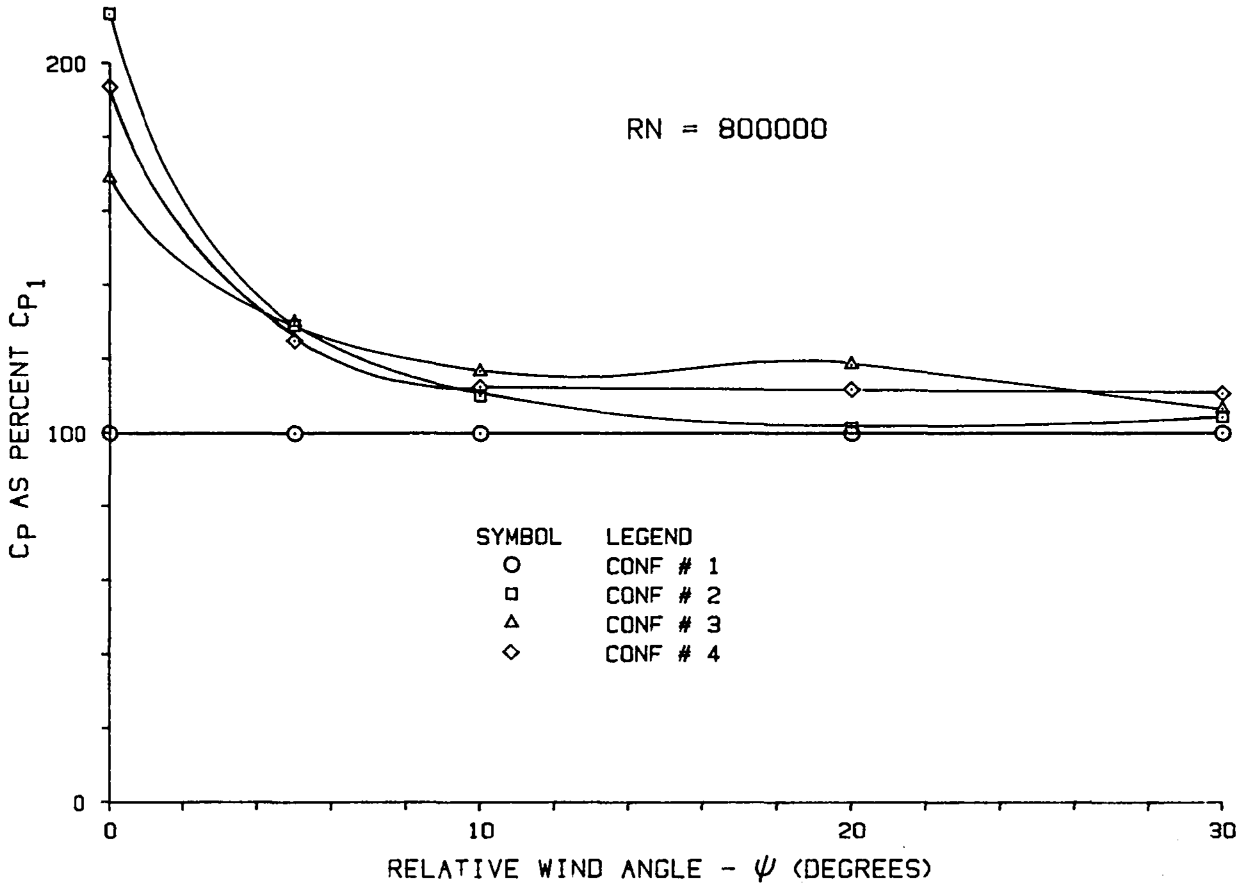


FIGURE 3.1.4 COMPARISON OF BASE PRESSURE COEFFICIENTS, CONFIGURATIONS 1,2,3,4

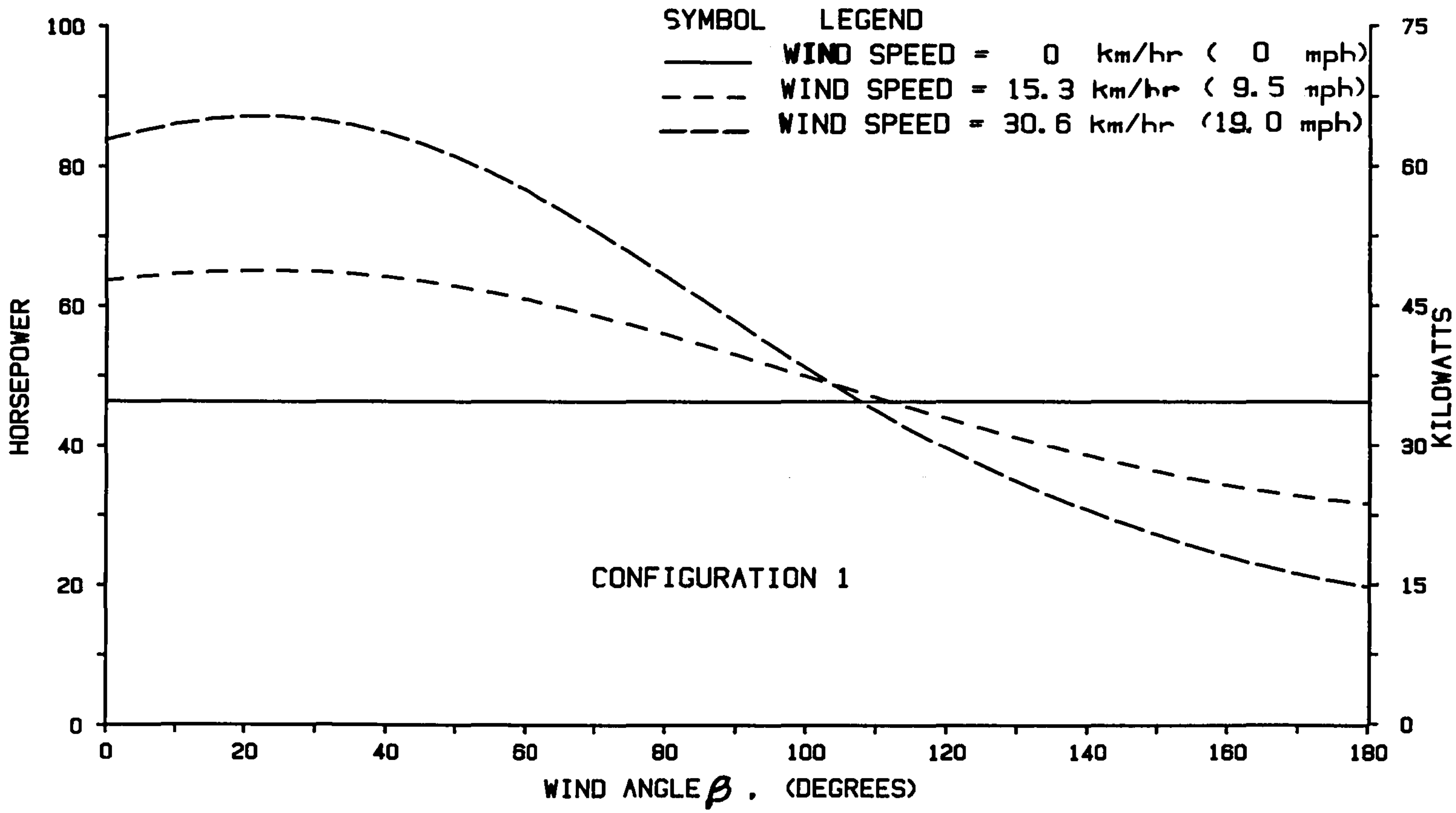


FIGURE 3.1.5 POWER REQUIRED TO OVERCOME AERODYNAMIC DRAG, CONFIGURATION 1

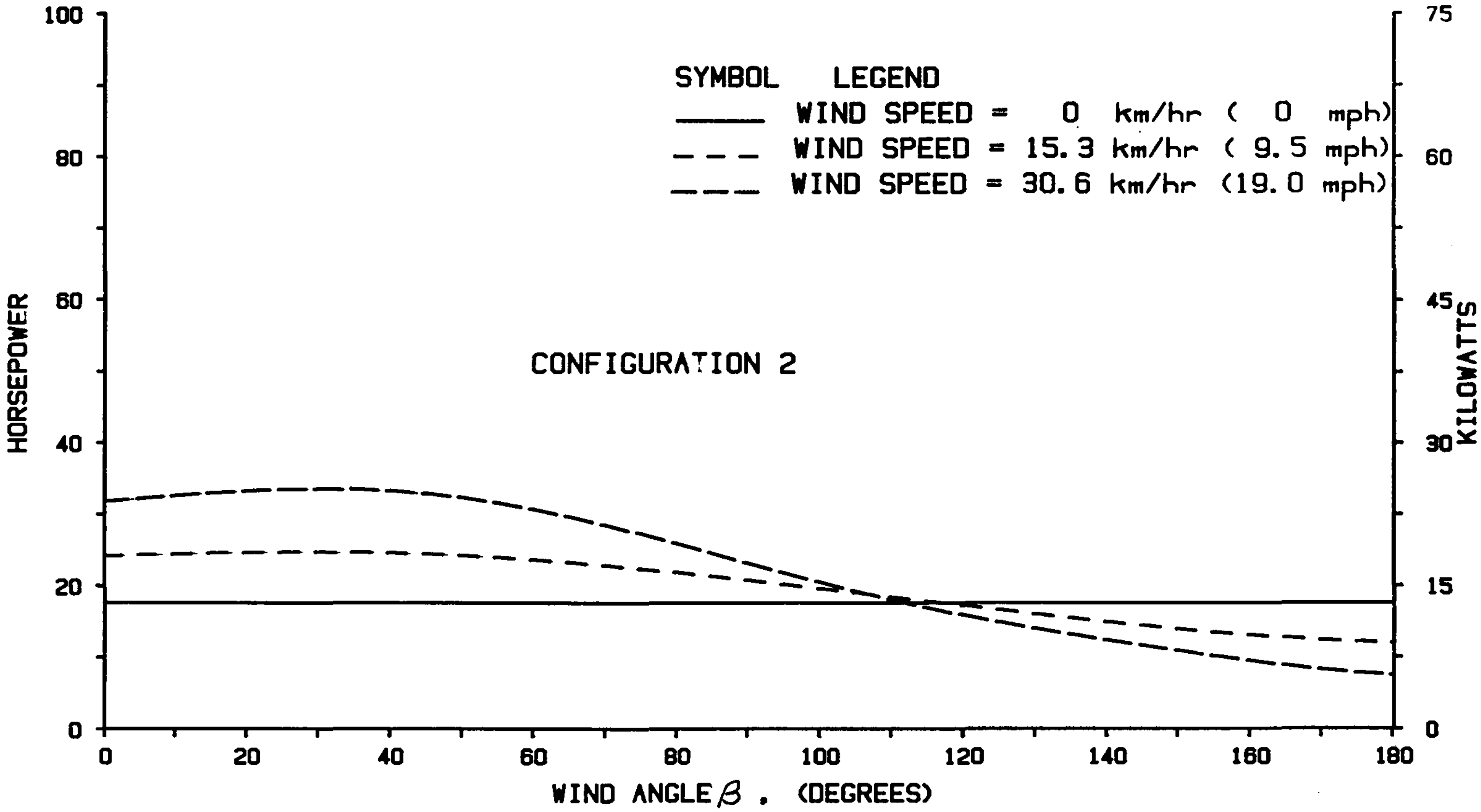


FIGURE 3.1.6 POWER REQUIRED TO OVERCOME AERODYNAMIC DRAG, CONFIGURATION 2

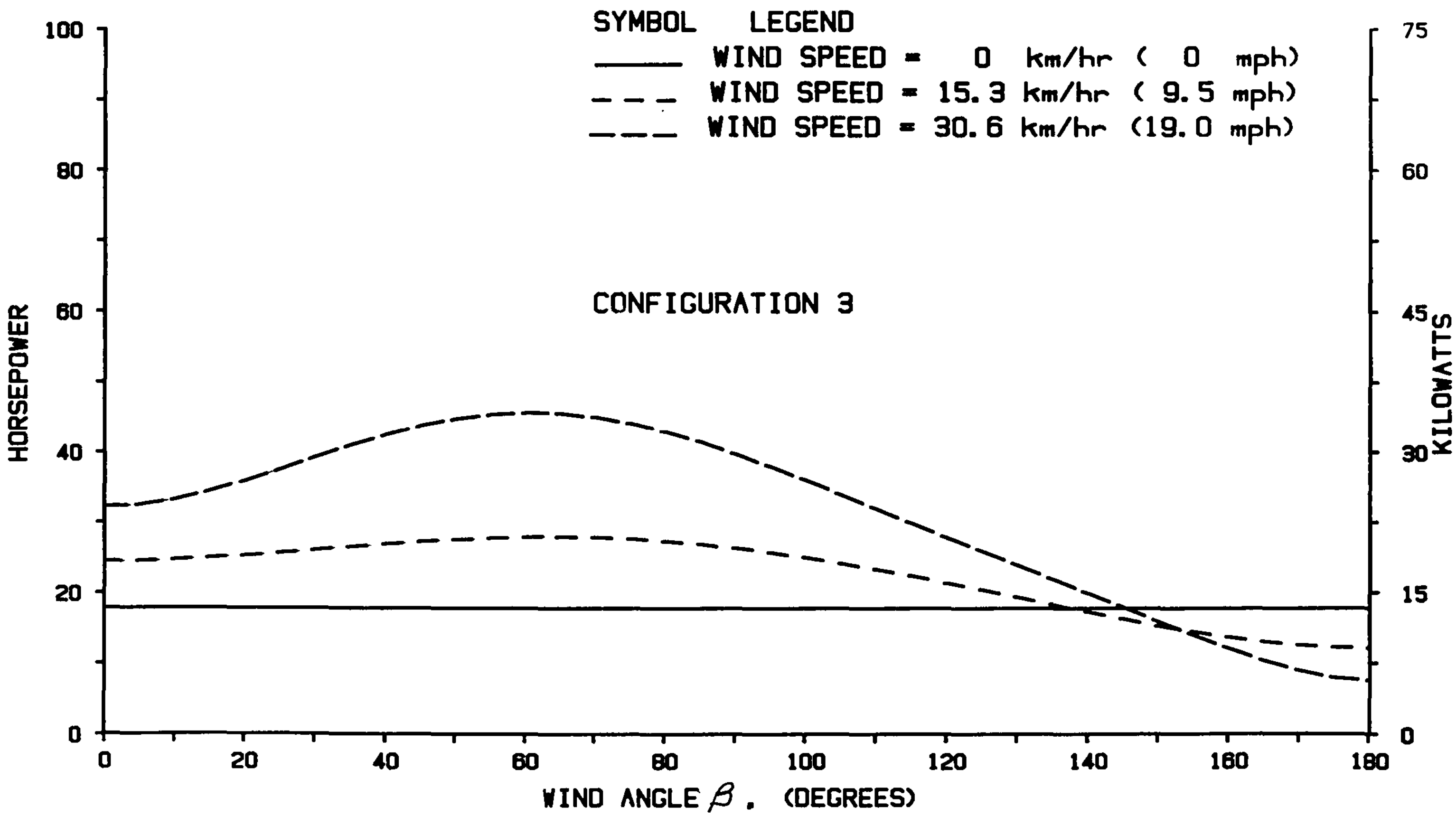


FIGURE 3.1.7 POWER REQUIRED TO OVERCOME AERODYNAMIC DRAG, CONFIGURATION 3

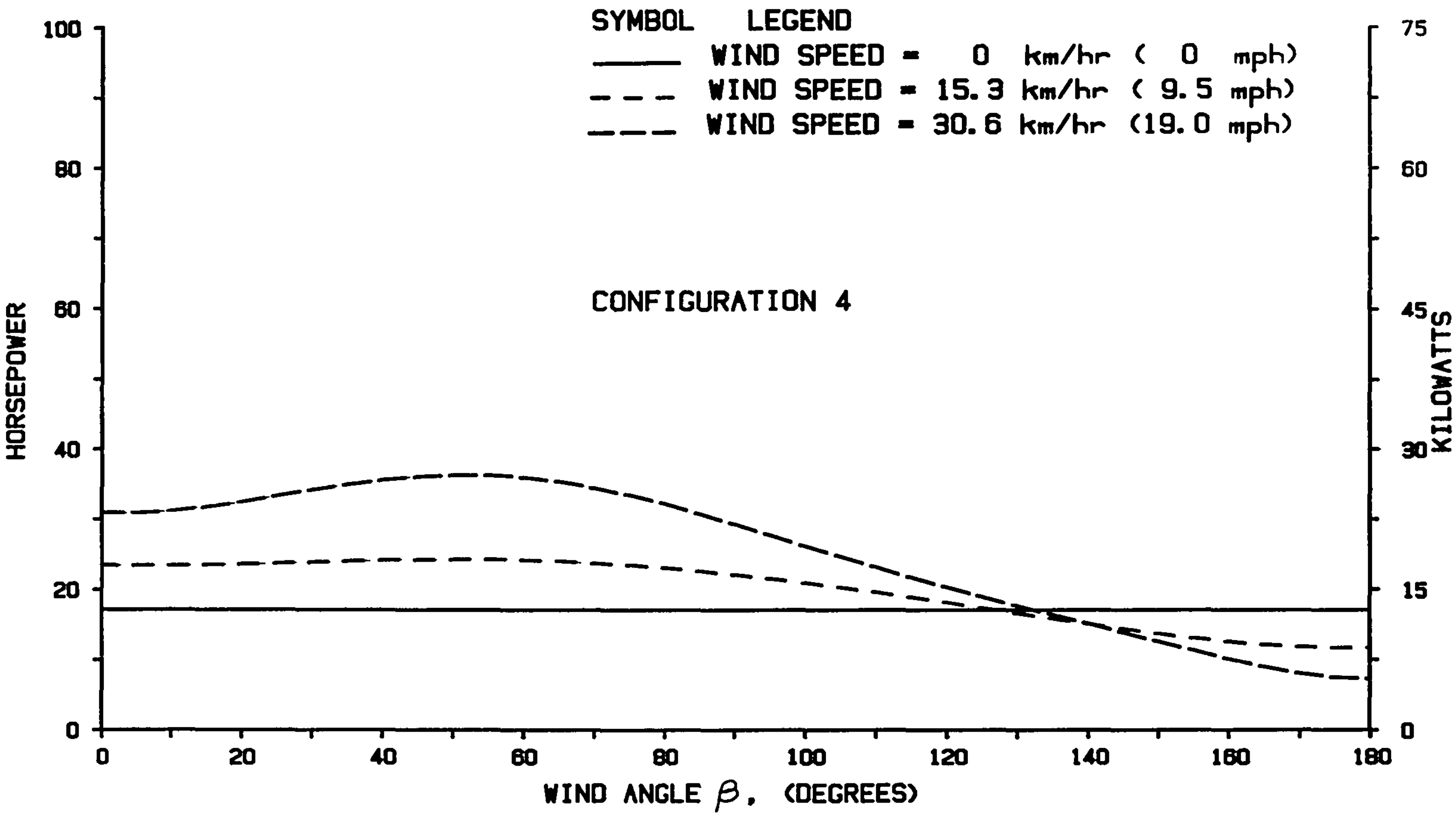


FIGURE 3.1.8 POWER REQUIRED TO OVERCOME AERODYNAMIC DRAG, CONFIGURATION 4

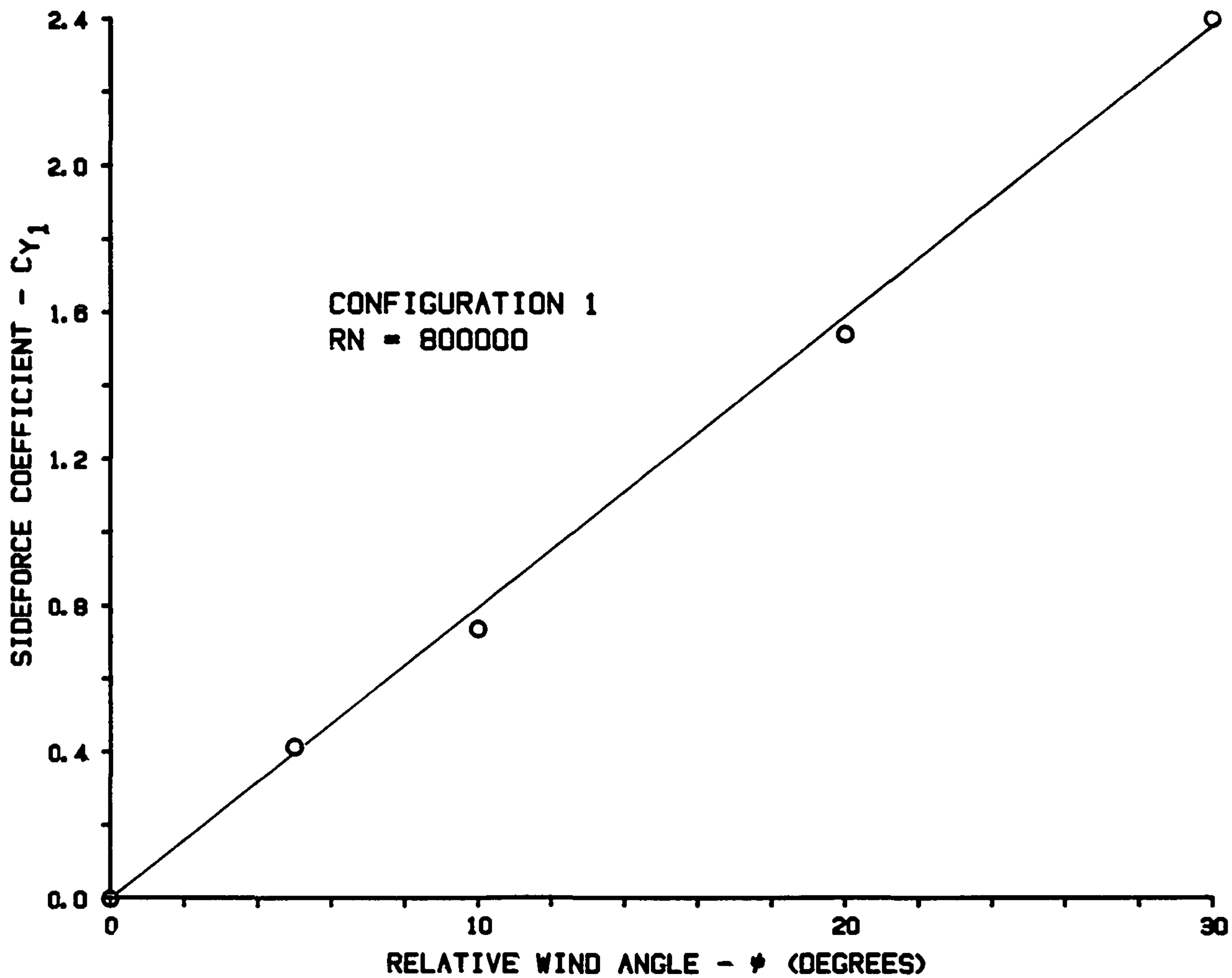


FIGURE 3.2.1 EFFECT OF RELATIVE WIND ANGLE ON SIDE FORCE COEFFICIENT C_{Y_1}

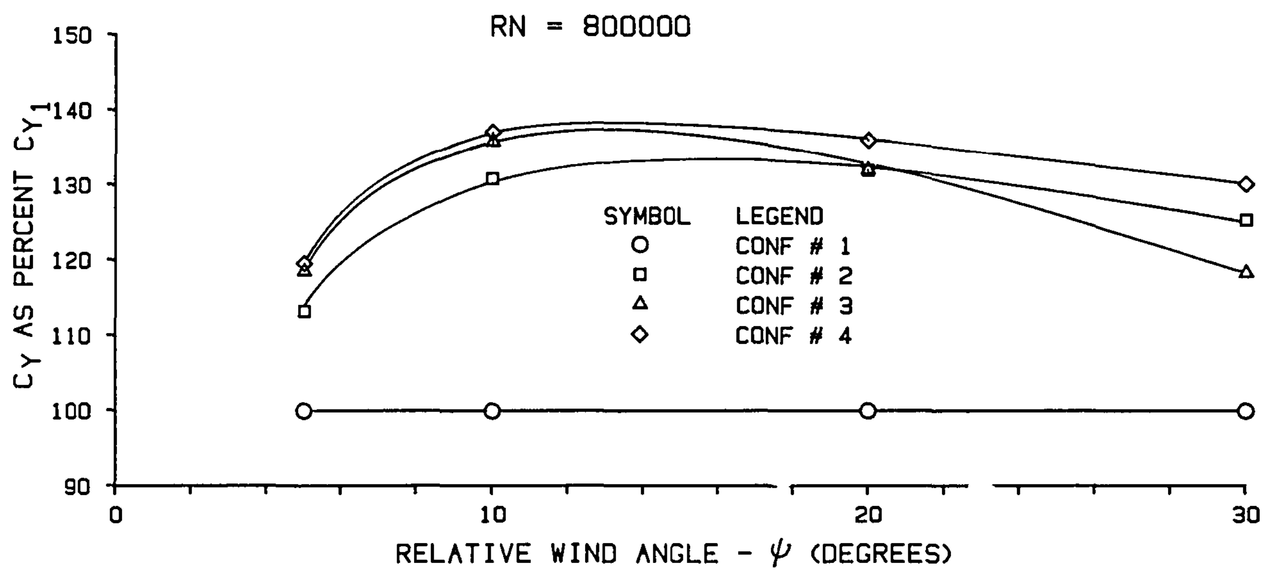


FIGURE 3.2.2 COMPARISON OF SIDE FORCE COEFFICIENTS, CONFIGURATIONS 1,2,3,4

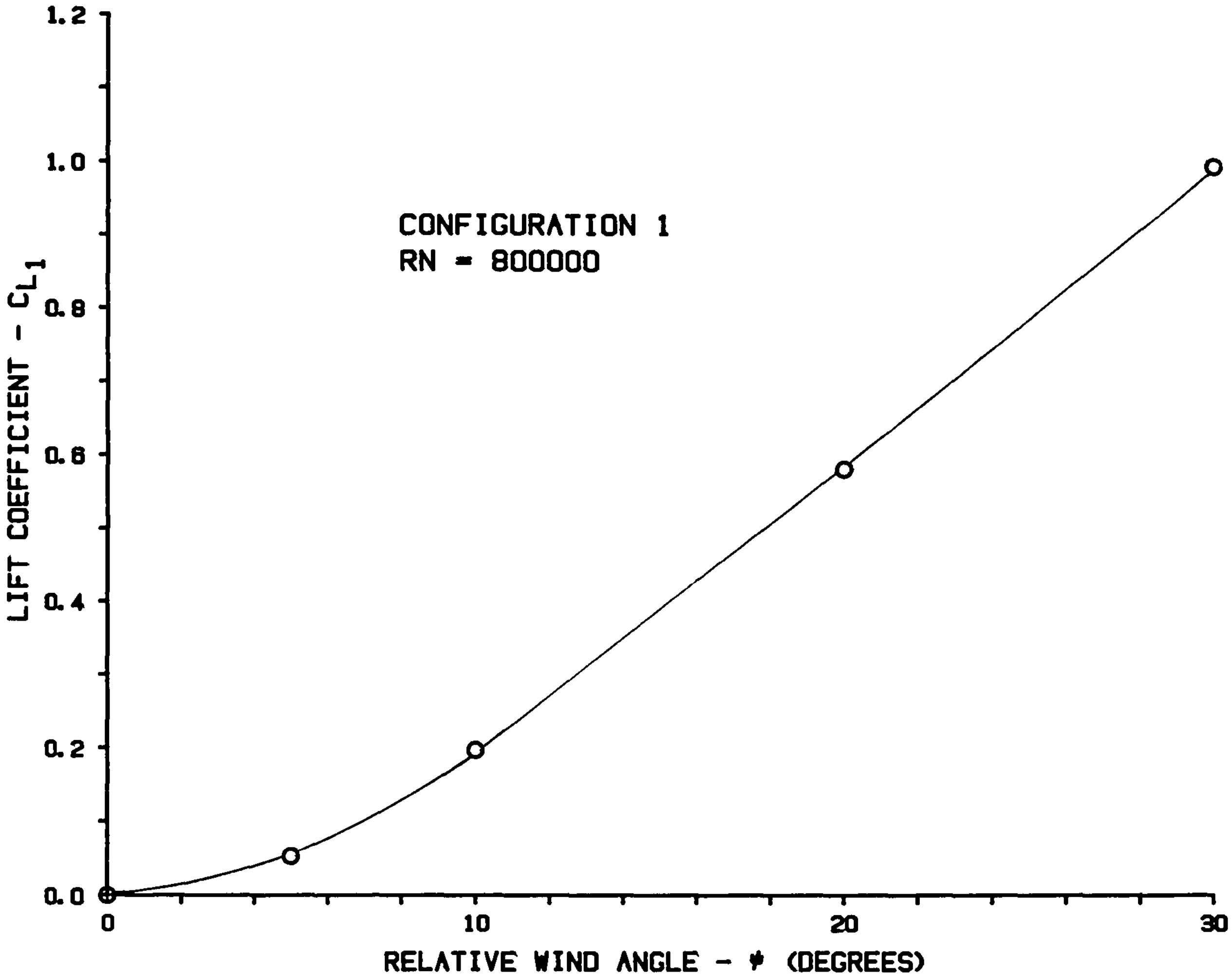


FIGURE 3.3.1 EFFECT OF RELATIVE WIND ANGLE ON LIFT COEFFICIENT C_{L_1}

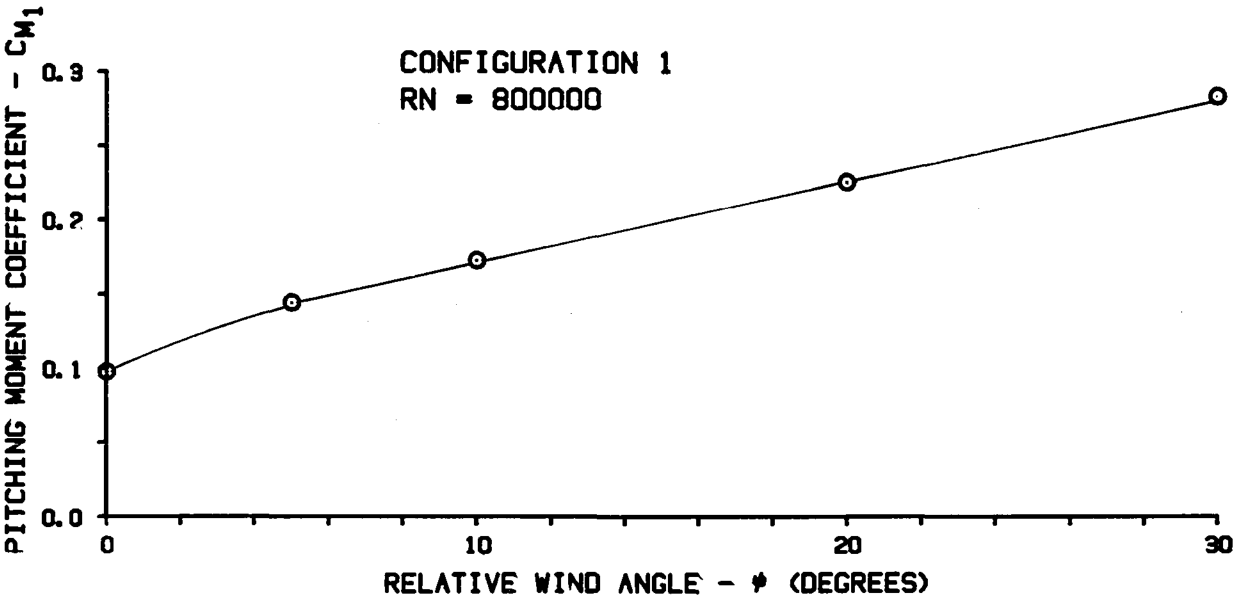


FIGURE 3.4.1 EFFECT OF RELATIVE WIND ANGLE ON PITCHING MOMENT COEFFICIENT C_{M_1}

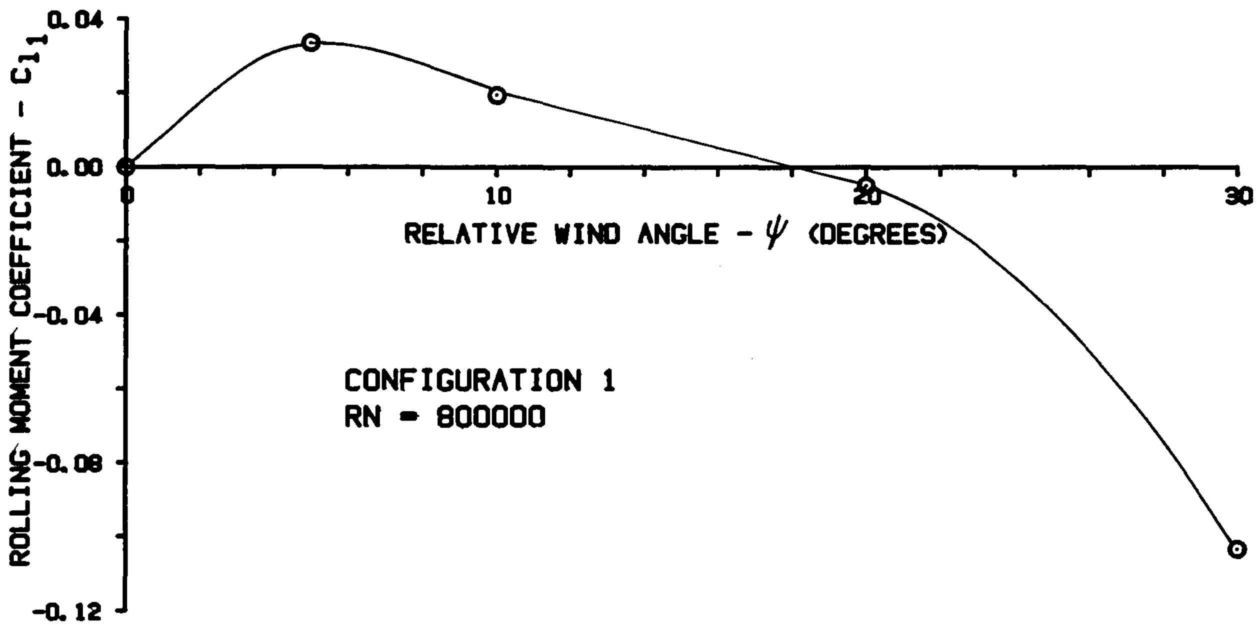


FIGURE 3.4.2 EFFECT OF RELATIVE WIND ANGLE ON ROLLING MOMENT COEFFICIENT C_{1_1}

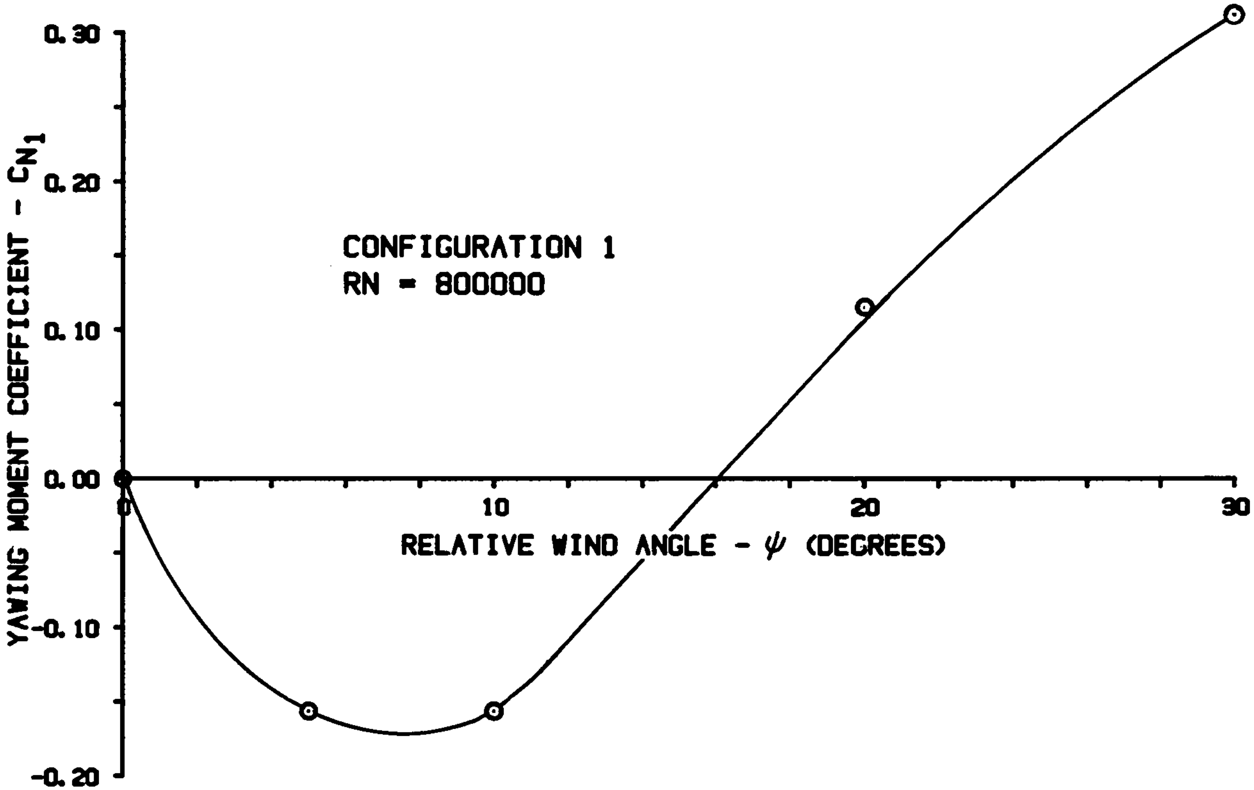


FIGURE 3.4.3 EFFECT OF RELATIVE WIND ANGLE ON YAWING MOMENT COEFFICIENT C_{N_1}

Table I. Drag coefficients, $R_N = 8 \times 10^5$

Configuration Number	Yaw Angles, ψ 0	5	10	20	30	Avg (0 to 10)	Avg (0 to 20)
1	0.975	1.035	1.121	1.212	1.171	1.044	1.086
2	0.369	0.399	0.435	0.486	0.389	0.401	0.422
3	0.373	0.431	0.556	0.864	0.892	0.453	0.556
4	0.362	0.390	0.473	0.632	0.524	0.408	0.464

Table II. Influence on drag coefficient of configuration changes and relative wind angles

CONFIGURATION		DRAG	
Parts Added	No. to No.	Zero wind[1] incremental change	Average wind[2] incremental change
Rounded		-----	-----
Front corners (4)	1 → 2	-62.2%	-61.1%
Flow-vanes (67°)	1 → 3	-61.7%	-48.8%
Flow-vanes (90°)	1 → 4	-62.9%	-57.3%

Note: 1. $R_N = 8 \times 10^5$

2. Qualitative-relative winds from $\psi = 0°$ to $\psi = 20°$

Table III. Comparison of tests run at Dryden Flight Research Center and the University of Kansas

Front Corners	DFRC (ref 2) Config.	DFRC (ref 2) C_D	KU (ref 3) Config.	KU (ref 3) C_D	KU (present tests) Config.	KU (present tests) C_D
Square	A(R)	1.130	1(S)	1.029	1(S)	.975
			2(R)	1.107		
Round	F(S)*	.463	4(S)	.426	2(S)	.369
% Decrease	$\frac{A-F}{A}$	59.0	$\frac{1-4}{1}$	58.6	$\frac{1-2}{1}$	62.2

Note:

1. All data at $\beta = 0°$
2. (R) signifies rough bottom,
   (S) signifies smooth bottom
3. Configuration F had 3/4 seal over underbody,
   *hence not completely smooth bottom
4. Height of body, hence Reference A, for present tests is larger than for References 2 and 3 by a factor of 1.2

Table IV. Base pressure coefficients, $R_N = 8 \times 10^5$

Configuration Number	Yaw angles, ψ 0	5	10	20	30
1	-.090	-.200	-.297	-.493	-.587
2	-.191	-.259	-.327	-.500	-.612
3	-.151	-.260	-.346	-.584	-.625
4	-.174	-.250	-.334	-.551	-.650

Table V. Average power required to overcome aerodynamic drag for all configurations tested

Configuration Number	Wind Speed km/hr (mph)		
	0	15.3 (9.5)	30.6 (19.0)
1	35(46)	38(51)	42(57)
2	13(18)	15(20)	17(22)
3	13(18)	17(23)	23(31)
4	13(17)	15(20)	19(25)

Note:
1. Ground speed = 88.6 km/hr (55 mph).
2. Power values are integrated over wind angles from 0° to 180°.
3. Power value units, KW(HP).
4. Power required values in table V are for "full-scale" vehicle, see note on page iv. Power required to overcome aerodynamic drag for a standard size motor-home would be 30% to 35% greater than for so-called "full-scale" vehicle of this study.

Table VI. Average fuel consumption per hour required to overcome aerodynamic drag for all configurations tested, for diesel

Configuration Number	Fuel Consumption liters/hr(gal/hr)	Fuel Savings liters/hr(gal/hr)	≈ % Saving*	≈ Cost Savings $/hr
1	9.8(2.6)	0.0(0.0)	0.0	0.00
2	3.8(1.0)	6.0(1.6)	61.2	1.62
3	4.3(1.1)	5.5(1.5)	56.0	1.50
4	3.8(1.0)	6.0(1.6)	61.2	1.62

Note:
1. Ground speed = 88.6 km/hr(55mph)
2. Wind speed = 15.3 km/hr(9.5mph)
3. BSFC = .2129 kg/kw-hr(.351 lbs/hp-hr) for diesel fuel, see page 5 for gasoline BSFC
4. Assumed fuel cost = $0.264/liter($1.00/gal)
5. *Percent saving of aerodynamic portion of fuel budget, not percent of total fuel budget
6. Volume of fuel consumed per hour and fuel savings per hour would be larger by a factor of about 1.7 for gasoline engine of comparable size
7. Assumed densities; Diesel, 0.836 kg/liter(6.96 lbs/gal); gasoline, 0.708 kg/liter (5.9 lbs/gal)
8. Fuel consumption and savings in table VI are for "full-scale" vehicle, see page iv. For a standard size motor-home the consumption and savings values would be from 30% to 35% greater.

Table VII. Side force coefficients, $R_N = 8 \times 10^5$

Configuration Number	Yaw angles, ψ				
	0	5	10	20	30
1	0 000	0.412	0.735	1.540	2.397
2	0.000	0.467	0.962	2.033	3.005
3	0.000	0.489	0.998	2.034	2.837
4	0.000	0.493	1.008	2.095	3.120

Table VIII. Lift coefficient, $R_N = 8 \times 10^5$

Configuration Number	Yaw angles, ψ				
	0	5	10	20	30
1	-0.000	-0.055	0.199	0.582	0.992
2	-0.028	0.024	0.098	0.399	0.850
3	-0.052	-0.012	0.101	0.561	1.111
4	-0.056	-0.015	0.076	0.424	0.919

Table IX. Pitching moment coefficients, $R_N = 8 \times 10^5$

Configuration Number	Yaw angles, ψ				
	0	5	10	20	30
1	0.097	0.144	0.173	0.226	0.283
2	0.092	0.083	0.084	0.149	0.261
3	0.083	0.087	0.114	0.228	0.318
4	0.080	0.080	0.090	0.188	0.316

Table X. Rolling moment coefficients, $R_N = 8 \times 10^5$

Configuration Number	Yaw angles, ψ 0	5	10	20	30
1	0 000	0.034	0.020	-0.005	-0.103
2	0.000	0.042	0.092	0.215	0.240
3	0.000	0.048	0.100	0.144	0.019
4	0.000	0.047	0.110	0.201	0.174

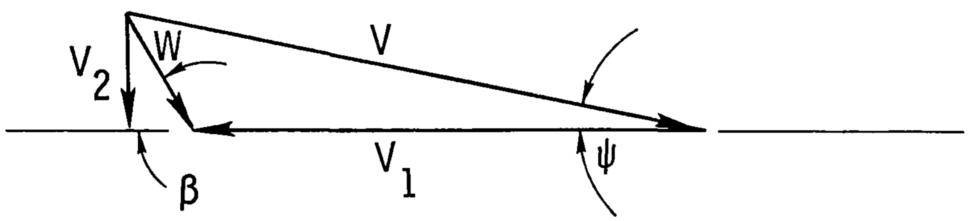
Table XI. Yawing moment coefficients, $R_N = 8 \times 10^5$

Configuration Number	Yaw angles, ψ 0	5	10	20	30
1	0 000	-0.156	-0.156	0.116	0.312
2	0.000	0.195	0.367	0.664	0.886
3	0.000	0.235	0.464	0.883	1.059
4	0.000	0.260	0.503	0.915	1.289

7. APPENDIX

POWER REQUIRED

The model data for Configuration 1 were applied to the full size prototype vehicle at road speed of 88.5 km/hr (55 mph). The wind component was rotated from 0° to 180° . Wind speeds used were 0, 15.3km/hr (9.5 mph), 30.6 km/hr (19.0 mph).



V = Relative wind speed

V_1 = Ground speed

W = Actual wind velocity

V_2 = Side wind velocity component

β = Wind angle relative to the vehicle path

ψ = Relative wind angle

7.1 Power to Overcome Aerodynamic Drag - Configuration 1

The power required is:

$$P = \frac{D\ V_1}{1000}\ \text{kw (Multiply by 1.341 = hp)}$$

where

$D = \frac{1}{2}\rho V^2 C_D A$

$A = 3.96\ m^2\ (42.8\ ft^2)$

$\rho = 1.226\ kg/m^3\ (.002378\ slugs/ft^3)$

C_D is taken from Figure 3.1.1 for Configuration 1 at approximate values of ψ.

Example:

$V_1 = 88.5$ km/hr or 24.58 m/sec (55 mph)

$W = 15.3$ km/hr or 4.25 m/sec (9.5 mph)

$\beta = 15°$

$\psi = 2.19°$

From Figure 3.1.1:

$C_{D_1} = .985$

Then:

$D = \frac{1}{2} \times 1.226 \times (28.71)^2\ (.985)\ (3.96)$

$D = 1970.9$ N

$$P = \frac{(1970.9)\ (24.58)}{1000} = 48.4\ \text{kw (65.0 hp)}$$

7.2 Power Required for Other Configurations

To find the power required for any other configuration:

1. Determine relative wind speed V and relative wind angle ψ.
2. Go to Figure 3.1.2. Find the percentage of C_{D_X} this configuration has of C_{D_1}.
3. Go to the power graph, Figure 3.1.5, and locate the power required for Configuration 1 at the wind angle β.
4. Multiply this value of power with C_{D_X}/C_{D_1}.

Example:

1. Configuration 2

Wind Speed W = 15.3 km/hr (9.5 mph)

Wind angle $\beta=15°$

Relative wind angle:

$$\psi = \mathrm{Tan}^{-1} \frac{W \sin\beta}{V_1 + W \cos\beta}$$

$$\psi = \mathrm{Tan}^{-1} \frac{15.3 \text{ km/hr} \sin 15^0}{88.5 \text{ km/hr} + 15.3 \text{ km/hr} \cos 15^0}$$

$$\psi = 2.19°$$

From Figure 3.1.2:

$$\frac{C_{D_1}}{C_{D_1}} = 38.0\% = \frac{P_2}{P_1}$$

From Figure 3.1.5

P_1 = 48.4 kw (65.0 hp) and P_2 = 18.4 kw (24.7 hp)

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15. Supplementary Notes

NASA Technical Monitor: Edwin J. Saltzman, Dryden Flight Research Center

16. Abstract

A wind tunnel investigation was conducted to determine the influence of several physical variables on the aerodynamic drag of a box-shaped vehicle model. The physical variables included built-in rounded front corners, and two different designs of add-on flow-vanes for the front of box-shaped vehicle with 67° and 90° of arc, respectively. Tests were conducted at yaw angles (relative wind angles) of 0°, 5°, 10°, 20°, and 30° and Reynolds numbers of 4.5×10^5 to 8.2×10^5 based upon the equivalent diameter of the model.

For a diesel powered vehicle, only slightly larger than a family van, the built-in rounded front corners provide a calculated fuel saving of about 6.0 liters per hour of driving (1.6 gallons per hour) at 88.6 km per hour (55 mph) in national average winds, as compared to the baseline vehicle having all square corners. The corresponding savings for a baseline vehicle to which front mounted flow-vanes were added is very competitive with the vehicle having the built-in rounded front corners. For a gasoline powered vehicle the volumetric fuel savings would be larger by a factor of about 1.7.

The fuel savings for a standard size motor home would be greater than for the above noted diesel or gasoline powered vehicles by from 30 percent to 35 percent because of the larger frontal area. Thus projected fuel savings for a standard size motor home powered by gasoline can approach 12.5 to 13.5 liters (3.3 to 3.6 gallons) for each hour of driving at highway speeds.

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