Semi-Annual Status Report

Research Grant No. NSG 4004

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An Investigation of Drag Reduction on Box-shaped Ground Vehicles

Center for Research, Inc.

University of Kansas

15 January 1976

Prepared by

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This letter report will summarize work accomplished since 31 July 1975, and the work to be performed during the remainder of the grant.

I. Work Accomplished

A. Testing and data reduction

Fifteen configurations, Figure 1, have been tested at five different Reynolds numbers and at wind angles of 0°, 5°, 10°, 20°, and 30°. All data have been reduced to coefficient form: drag, lift, side force, roll, pitch, and yaw. The drag data have been plotted.

B. Results

The drag coefficients were plotted against Reynolds numbers based on an effective diameter for each configuration at each wind angle, Figures 2 through 18. Configurations 1 and 5 were used as reference configurations. These plots indicate the following:

1. At zero wind angle the effect of Reynolds number on the drag coefficient is small except for configuration 13 (rough bottom).
2. Except for configurations with a rough bottom the drag coefficient variation with Reynolds number was the greatest at the large wind angles.
3. The configurations with a rough bottom (2, 6, 13) exhibited a sharp drop in drag coefficient at the highest Reynolds number at several wind angles.
4. All configurations with square longitudinal corners exhibited a maximum drag coefficient at a 20° wind angle. Those configurations with rounded longitudinal corners exhibited a maximum drag coefficient at a 30° wind angle.

The effect of wind angle on the drag coefficient for configuration 1 is shown in Figure 19 for a Reynolds number (R_D) of 8×10^5. These values were used to normalize the drag coefficients of all other configurations. Comparison graphs are shown in Figure 20 through 25. Configurations 1 and 5 are used for references.

The comparisons indicate the following:

1. The rough bottom added from 8 to 14 percent of configuration 1 drag to the drag of the smooth bottom configurations. The exception occurred at about a 5° wind angle and the highest Reynolds number R_D. Apparently a flow separation change occurred either from the front wheel or the skirt around

the rough bottom which interacted with the rough bottom to decrease drag.

2. The configuration 5 drag coefficient (rounded front and rear ends with square longitudinal corners) was about 40% that of configuration 1 and 37% of configuation 2.
3. Configuration 5 was superior to the configurations with rounded front, rear and longitudinal corners (7, 9, 10, 11, and 12).
4. Configuation 15 (7 with streamlined rear end) was superior to all other configuations. It did exhibit the increase in drag coefficient with wind angle which was characteristic of all configurations with the rounded upper longitudinal corners.
5. The effect of the tow hitch, configuation 13 (2 plus hitch) and 14 (4 plus hitch), was very small except at a 5° wind angle for 13 and 30° wind angle for 14.
6. The drag coefficient of configuration 3 (round front vertical and upper front) was about 45% that of configuration 1.
7. By rounding the lower front horizontal corner, Configuration 4, the drag coefficient was about 42% of configuration 1.
8. Rounding the rear end, configuration 5, reduced the drag coefficient to about 40% of configuration 1.

In summary the rough bottom increased drag about 10% over a smooth bottom, rounded front end reduced the drag 58%, and the streamlined rear end reduced the drag 20%. The best configuration would appear to be configuration 15 with square longitudinal corners.

Table I presents a comparison between comparable data points made by the NASA Flight Research Center on the prototype and the windtunnel models.

Configurations A (NASA), 2 (KU) (square corners and rough underbody data points fall well within the limits of measurement errors. This seems to confirm that Reynolds number for a completely bluff body is negligible. The other comparative configurations exhibit a difference which is slightly outside the measurement error limits. This indicates a small Reynolds number effect on the more streamline shapes.

Figure 26 shows the power required to overcome the aerodynamic drag of configuration 1 traveling at a constant ground speed of 55 mph. The selected wind speeds of 0, 10, and 20 mph were used as representative in computing the horsepower. The horsepower required for the other configurations may be obtained by multiplying Figure 26 values by the percentage values in Figures 20 through 25.

Table. 1 Drag coefficient Comparisons

FRC (No wind)					KU (No Wind)						Difference	
Config	Front	Rear	Under body	C_D	Config	Front	Rear	Under body	C_D $R_D = 3\times10^5$	C_D $R_D = 8\times10^5$	% $R_D = 3\times10^5$	% $R_D = 8\times10^5$
A	□	□	Rough	1.13	2	□	□	Rough	1.17	1.11	+2.6	-1.7
C	○	⊘	Rough	.520	6	○	○	Rough	.575	.551	+10.6	+5.9
D	○	○	Seal	.440	5	○	○	Smooth	.445	.410	+1.0	-6.8
F	○	□	3/4 seal	.465	7	○	□	Smooth	.435	.425	-6.0	-8.2

II. Work to be accomplished

A. Data Analysis

The side force, lift, roll, pitch, and yaw data will be plotted in the same manner as the drag data. Further analysis of the drag data together with these other components will be made.

B. Additional tests

Additional tests which are contemplated at this time are given in Figure 27. Configuration 16 is a balsa circular add-on to the four front corners of configuration 1. Configuration 17 through 20 are add-ons to the rear of configuration 4. Configuration 21 is with configuration 6 with the rough under body sealed.

C. Final Report

The final report will include an analysis and report of all data.

CONFIG. NO.	FRONT VERTICAL	FRONT UPPER HORIZONTAL	FRONT LOWER HORIZONTAL	REAR VERTICAL	REAR UPPER HORIZONTAL	REAR LOWER HORIZONTAL	UNDER BODY	UPPER LONGITUD.	TURNING VANES
1	□	□	□	□	□	□	Smooth	□	No
2	□	□	□	□	□	□	Rough	□	No
3	○	○	□	□	□	□	Smooth	□	No
4	○	○	○	□	□	□	Smooth	□	No
5	○	○	○	○	○	○	Smooth	□	No
6	○	○	○	○	○	○	Rough	□	No
7	○	○	○	○	○	○	Smooth	○	No
8	○	○	□	○	○	□	Smooth	□	No
9	○	○	□	○	○	□	Smooth	○	No
10	*(V)	*(V)	□	*(V)	*(V)	□	Smooth	*(V)	Yes*
11	*(V)	*(V)	□	*(V)	*(V)	□	Smooth	○	Yes*
12	*(V)	*(V)	□	○	○	□	Smooth	○	Yes*
13	□	□	□	□	□	□	Rough	□	Tow No/Hitch
14	○	○	○	□	□	□	Smooth	□	Tow No/Hitch
15	○	○	○	STREAMLINING			Smooth	○	No

□ Square Corners ○ Round Corners (V) Turning vane Location

Figure 1. Configuration chart

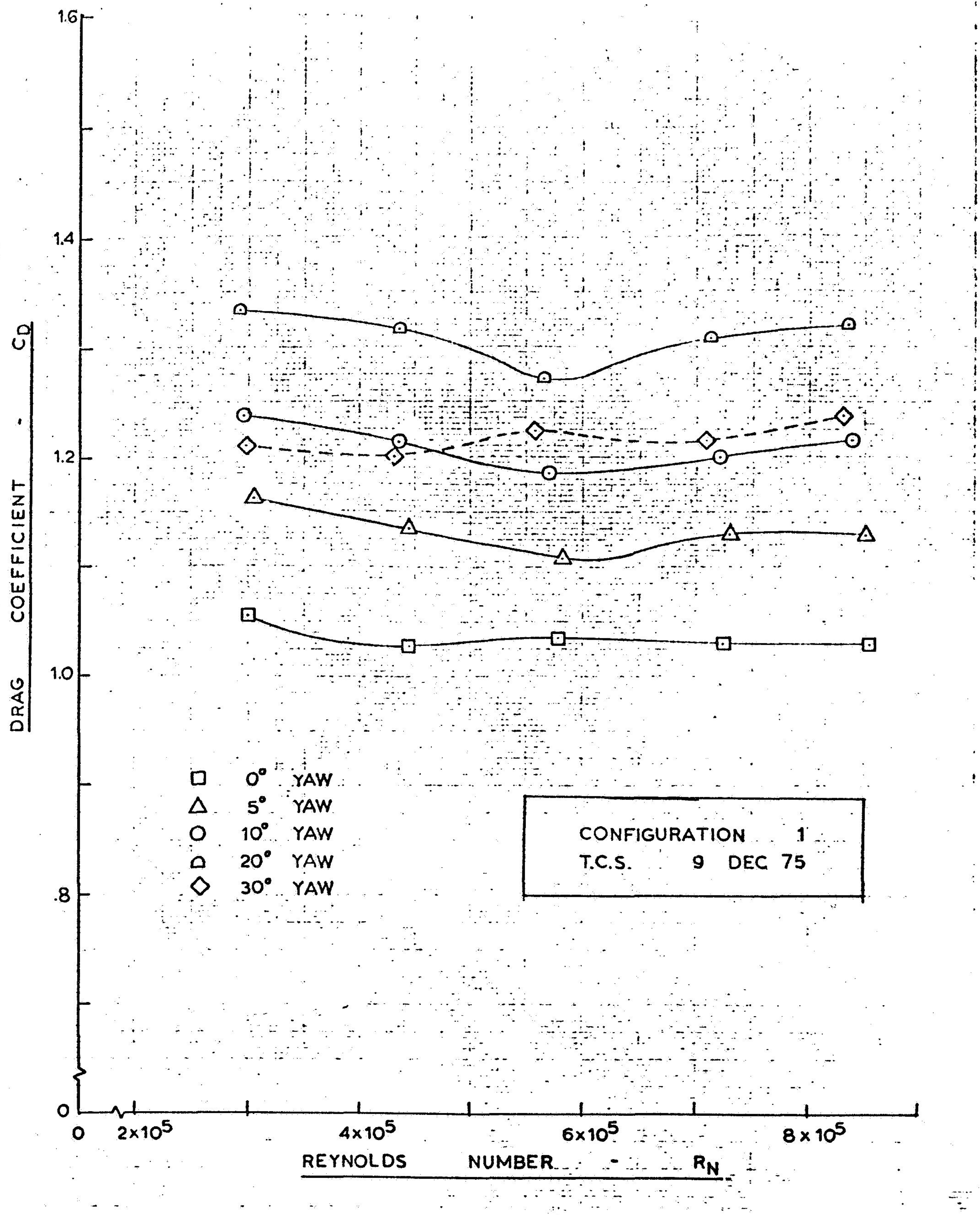


Figure 2. Effect of Reynolds number on drag coefficient-Configuration 1.

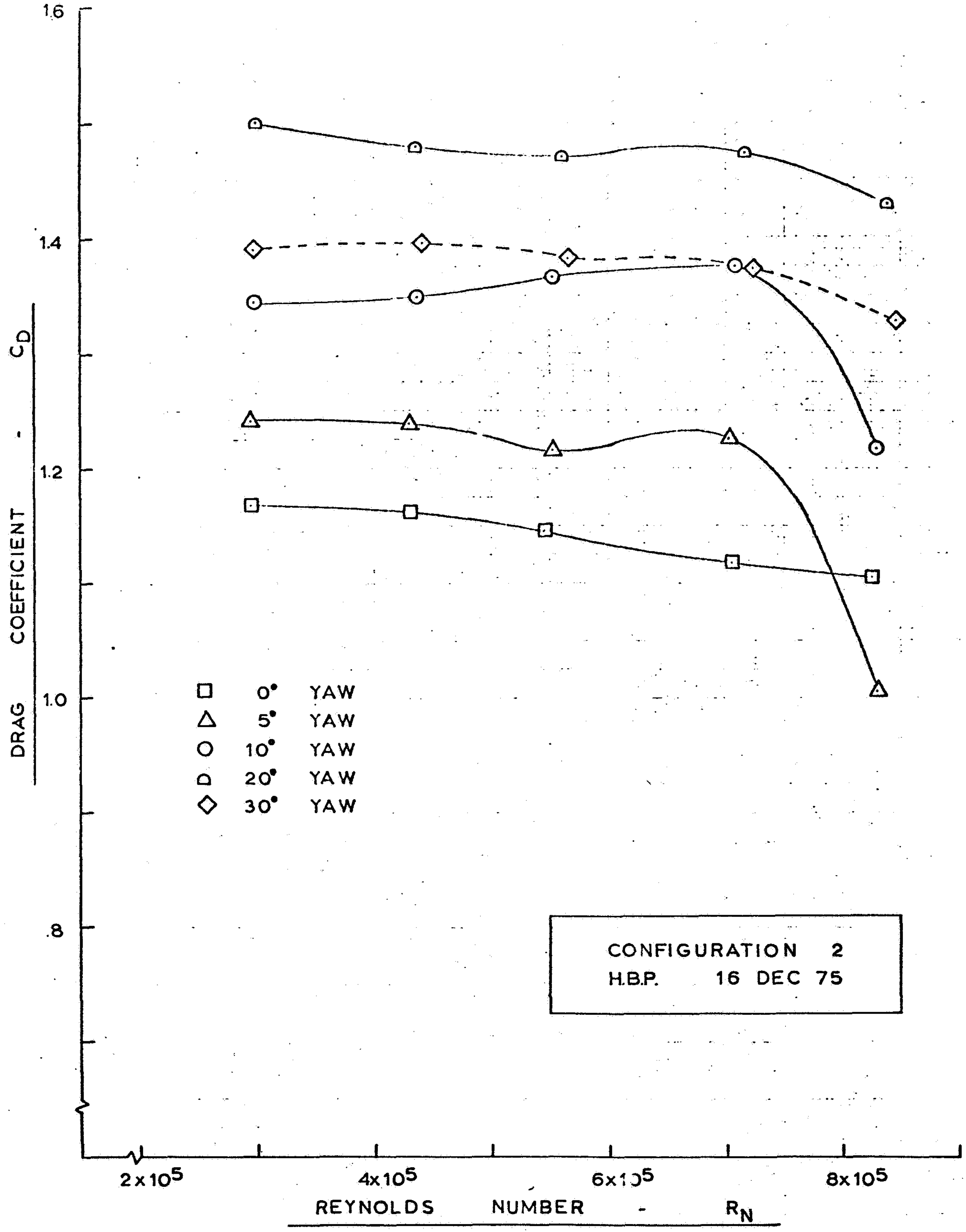


Figure 3. Effect of Reynolds number on drag coefficient-Configuration 2.

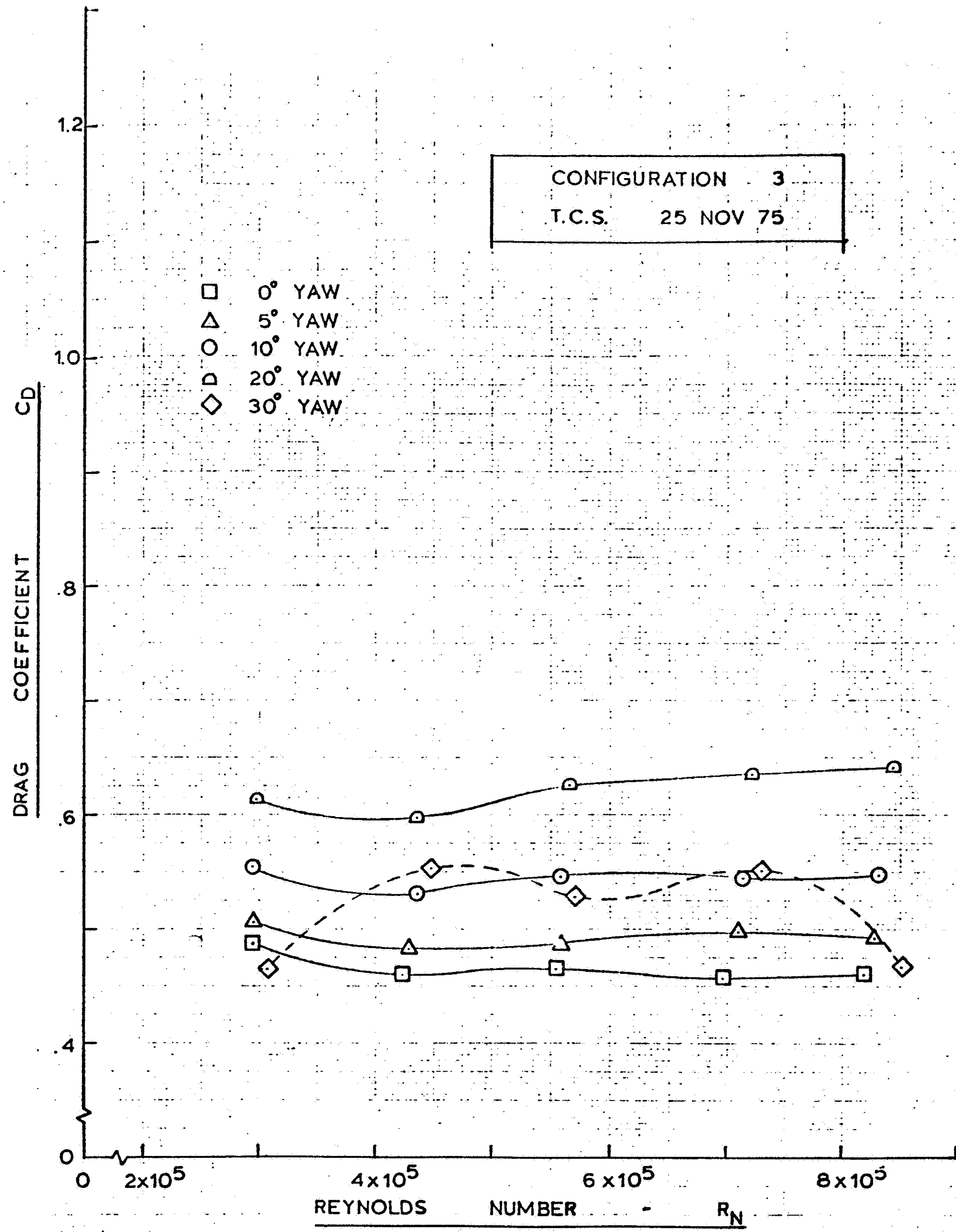


Figure 4. Effect of Reynolds number on drag coefficient-Configuration 3.

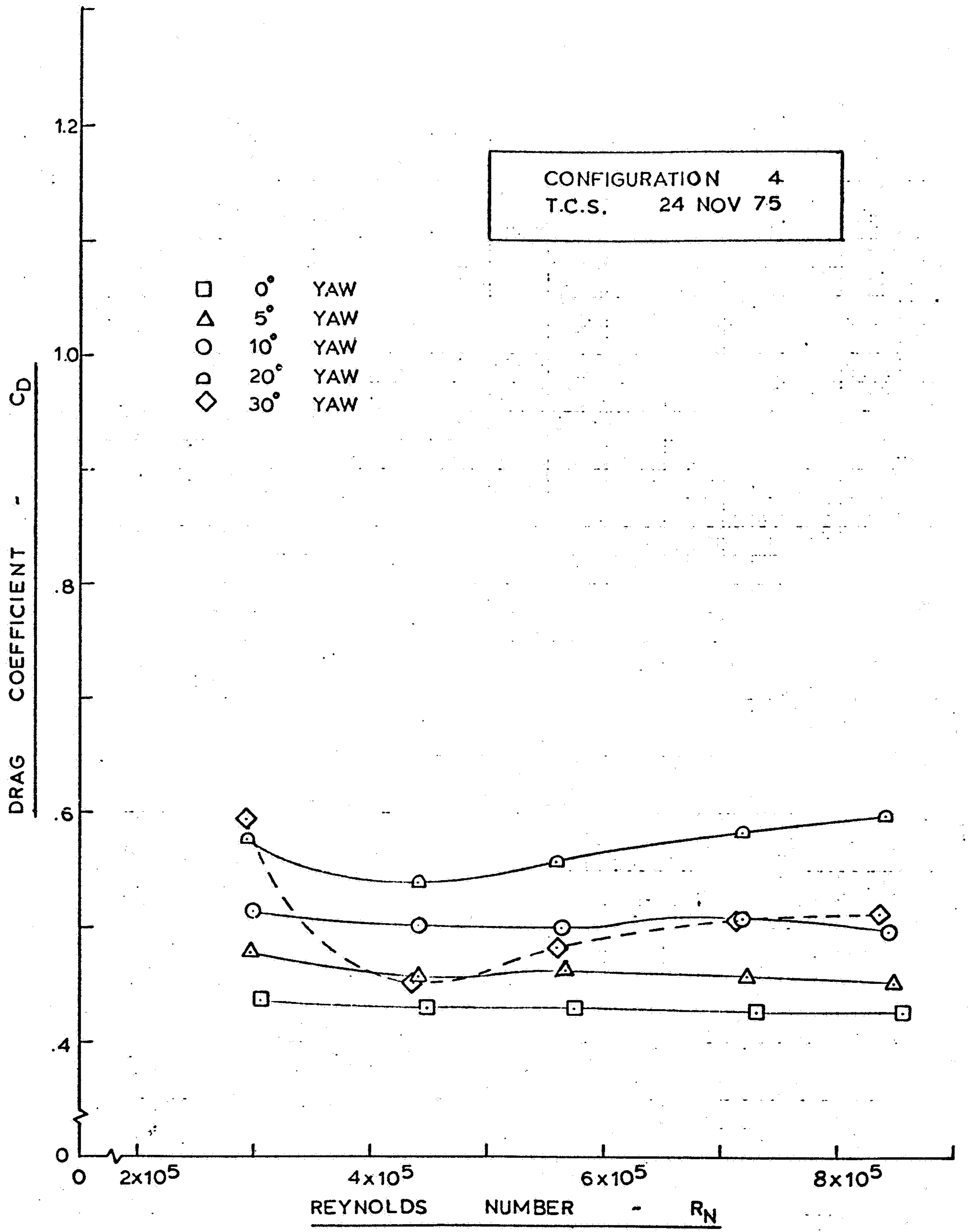


Figure 5. Effect of Reynolds number on drag coefficient-Configuration 4.

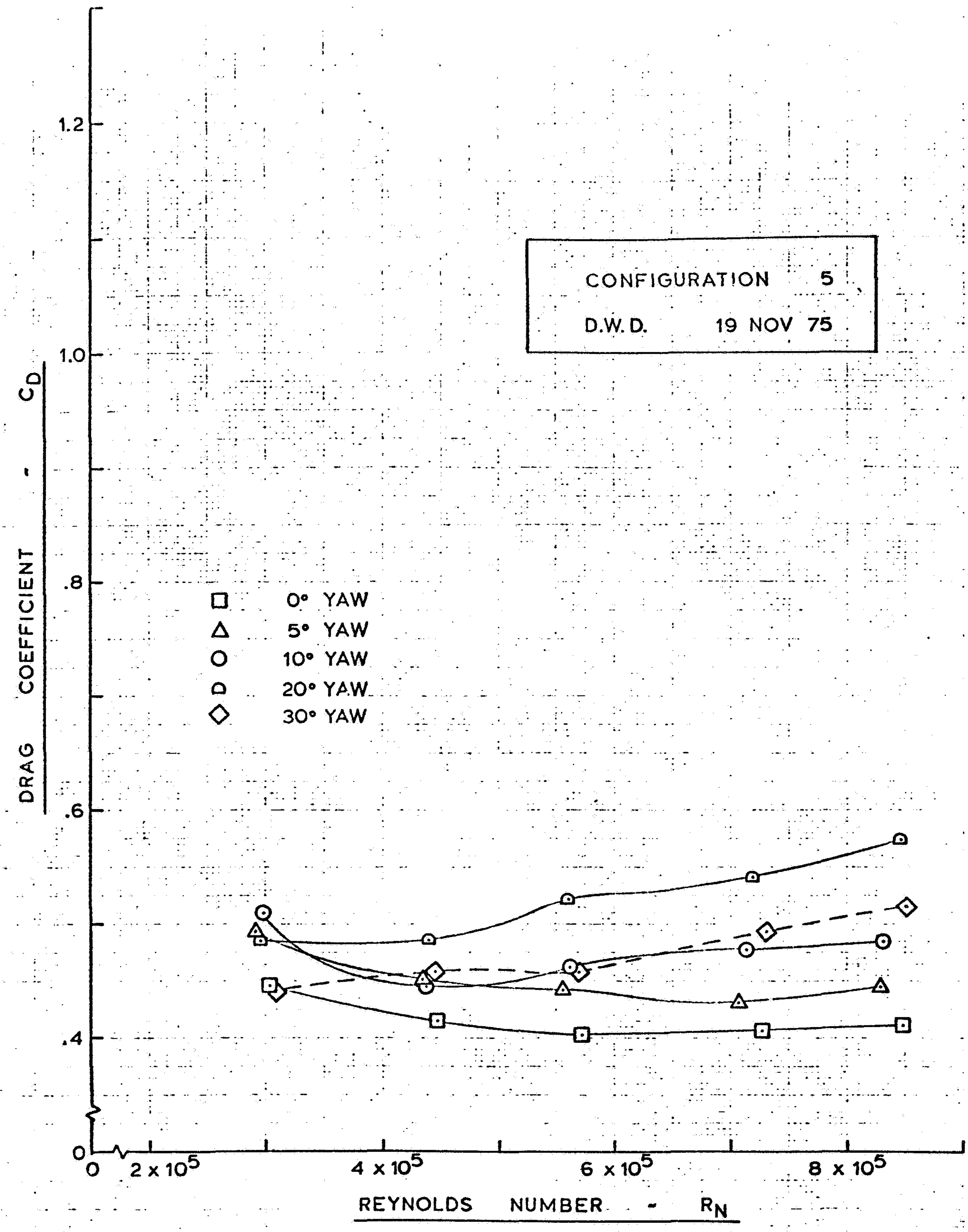


Figure 6. Effect of Reynolds number on drag coefficient-Configuration 5.

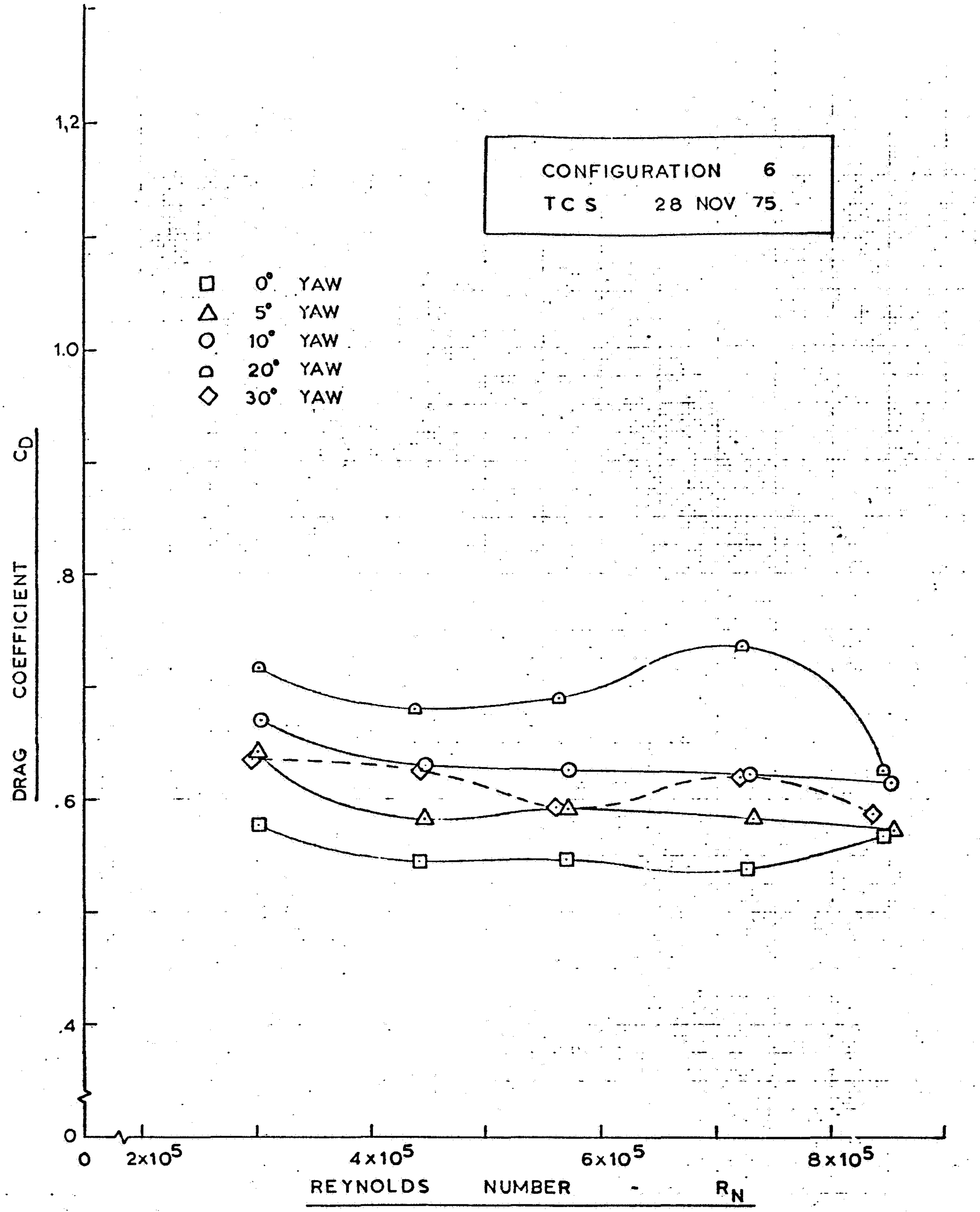


Figure 7. Effect of Reynolds number on drag coefficient-Configuration 6.

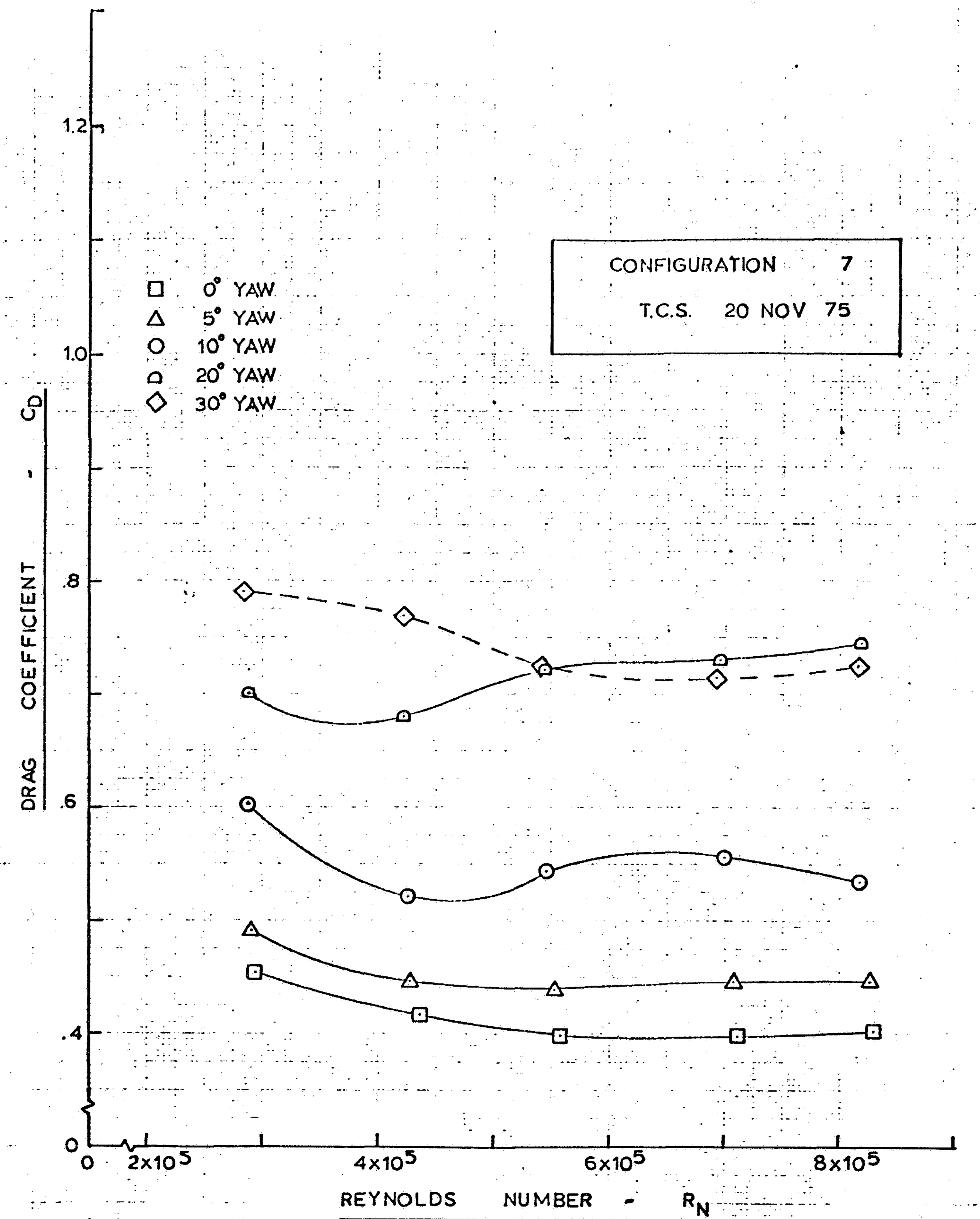


Figure 8. Effect of Reynolds number on drag coefficient-Configuration 7.

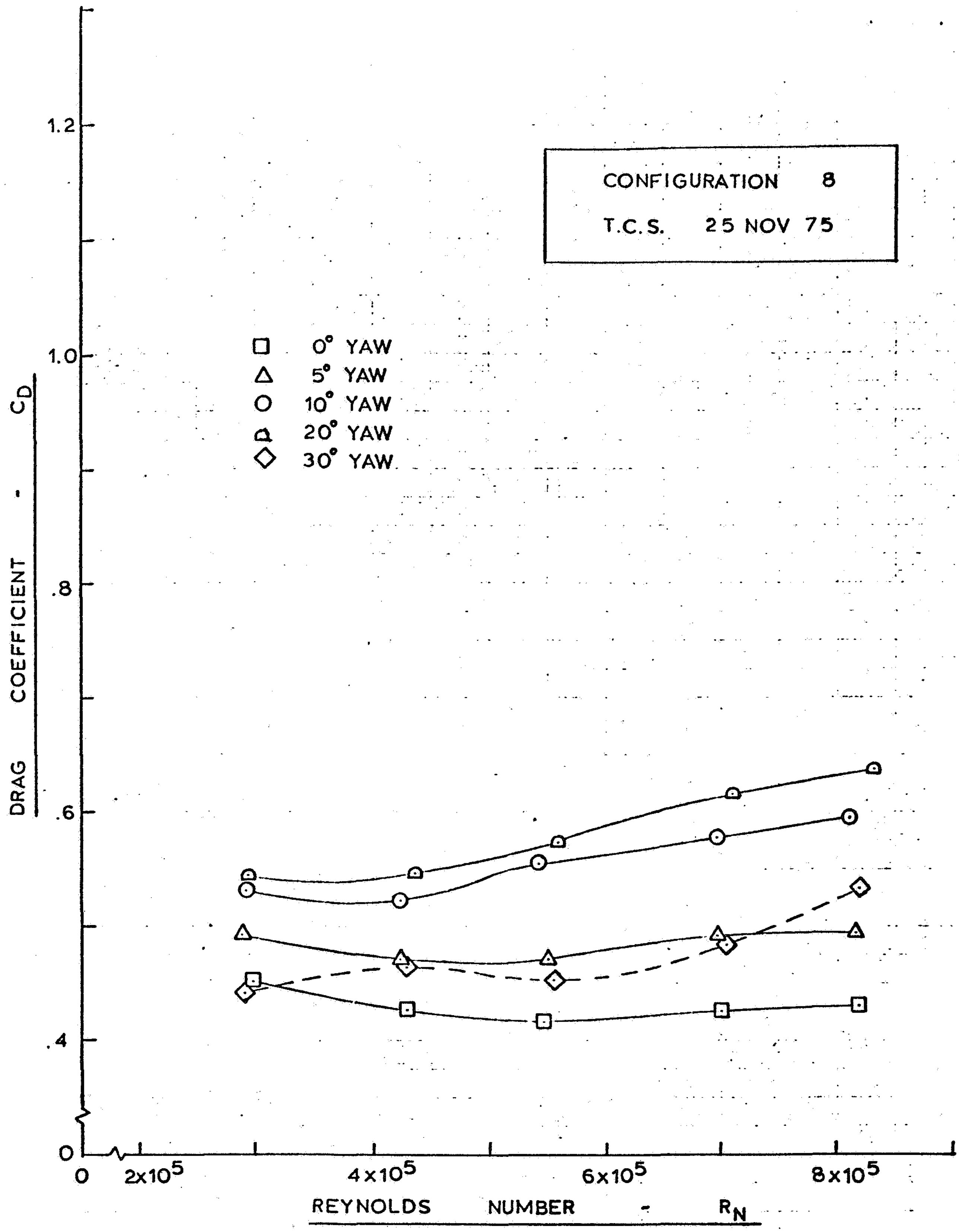


Figure 9. Effect of Reynolds number on drag coefficient-Configuration 8.

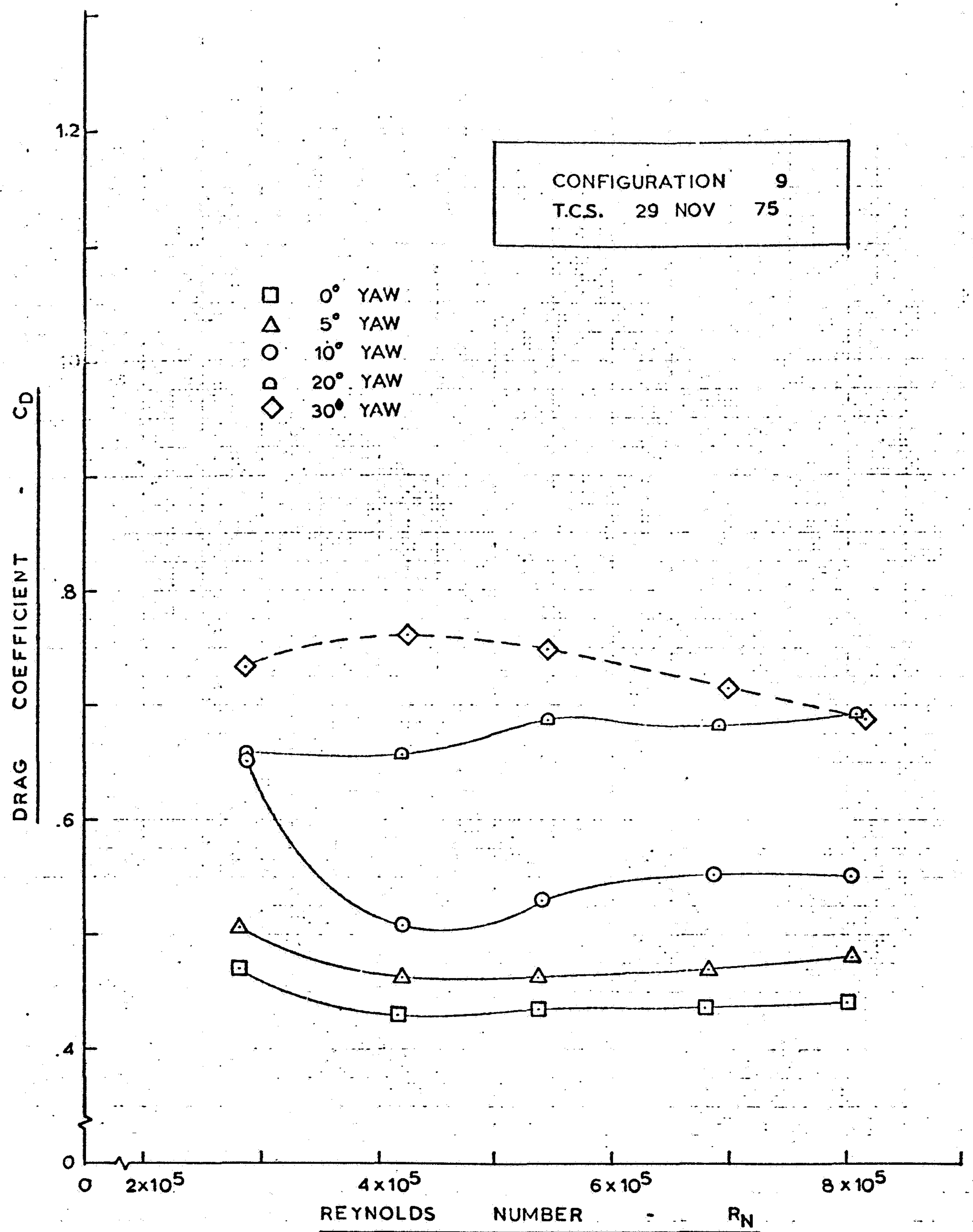


Figure 10. Effect of Reynolds number on drag coefficient-Configuration 9.

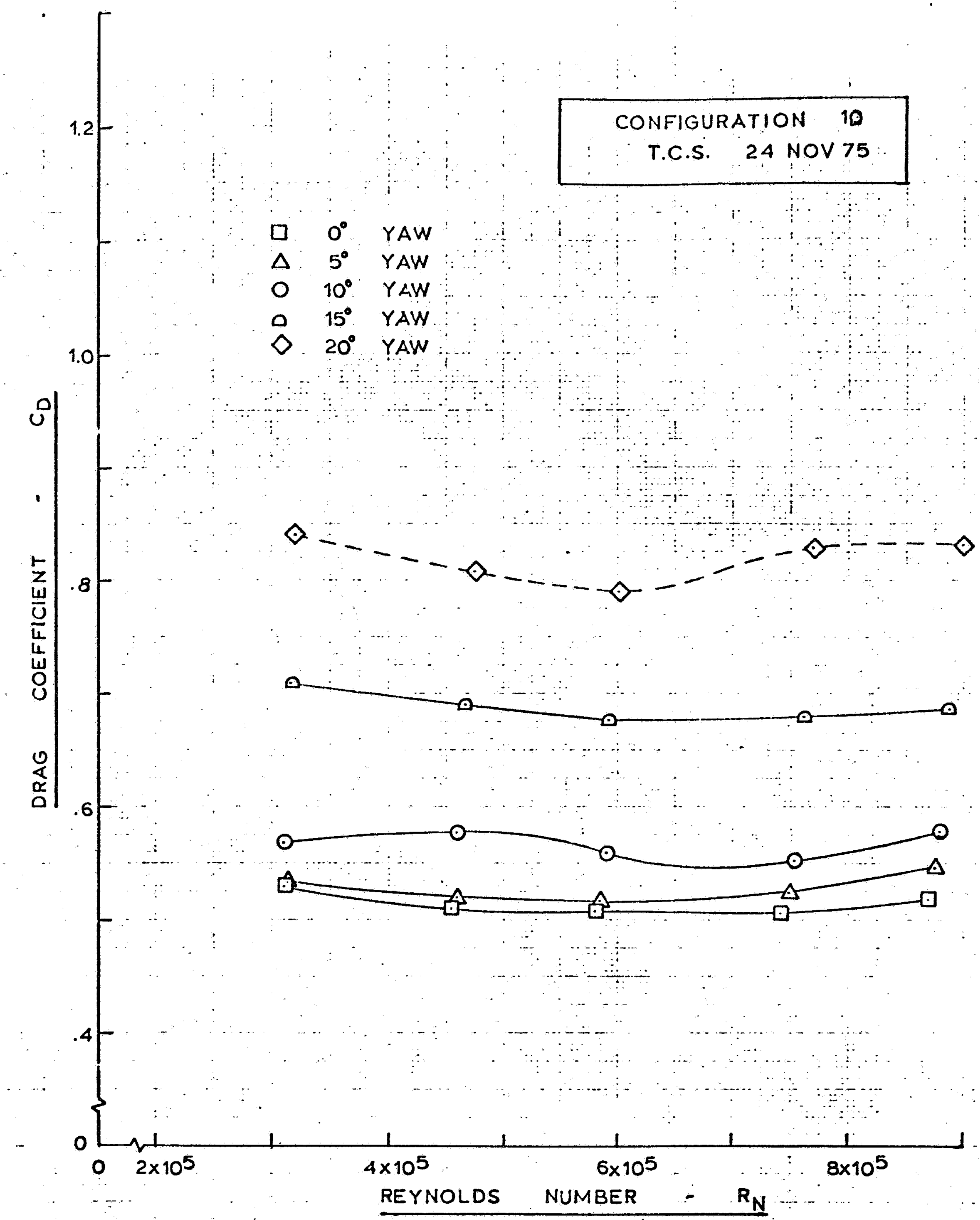


Figure 11. Effect of Reynolds number on drag coefficient-Configuration 10.

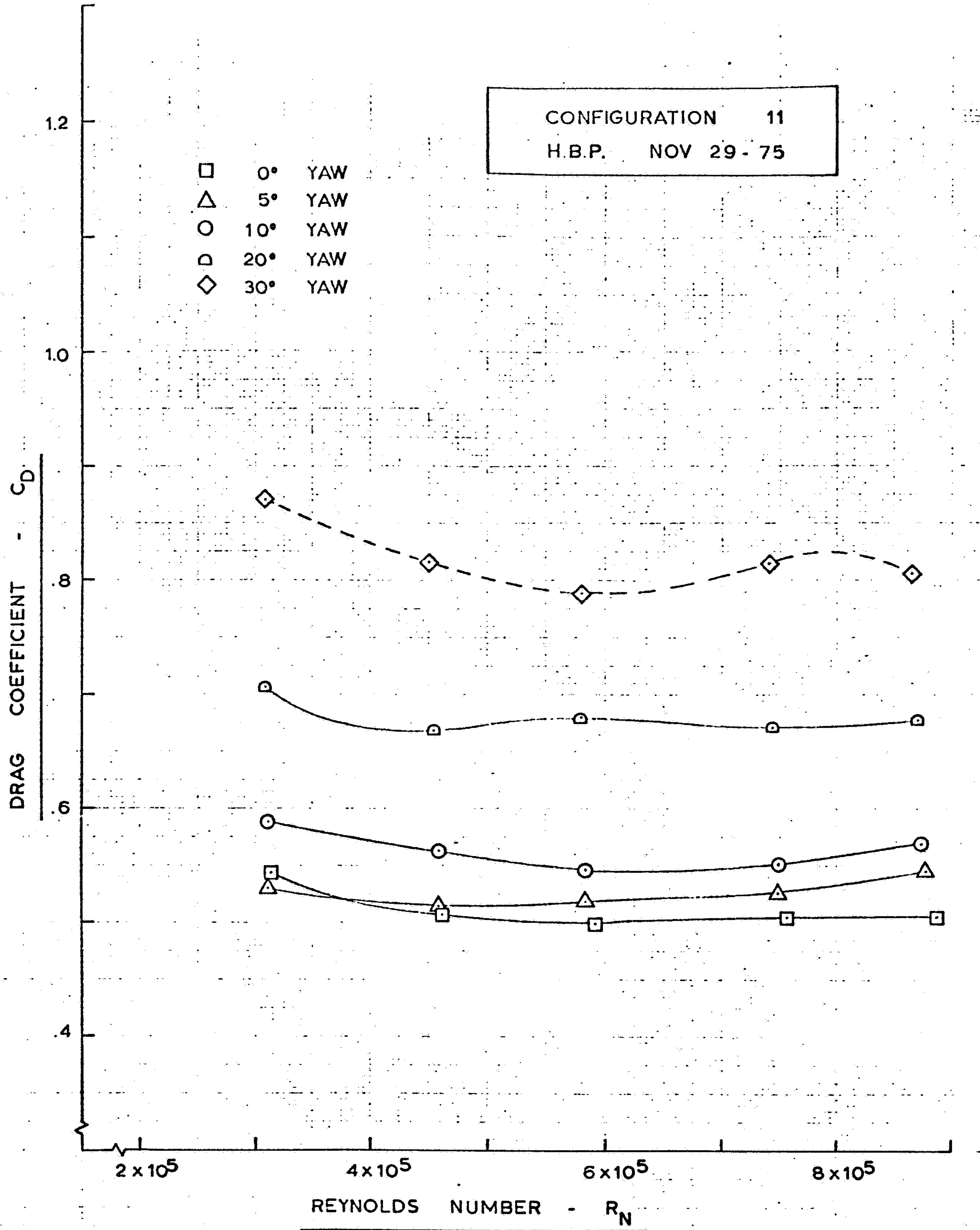


Figure 12. Effect of Reynolds number on drag coefficient-Configuration 11.

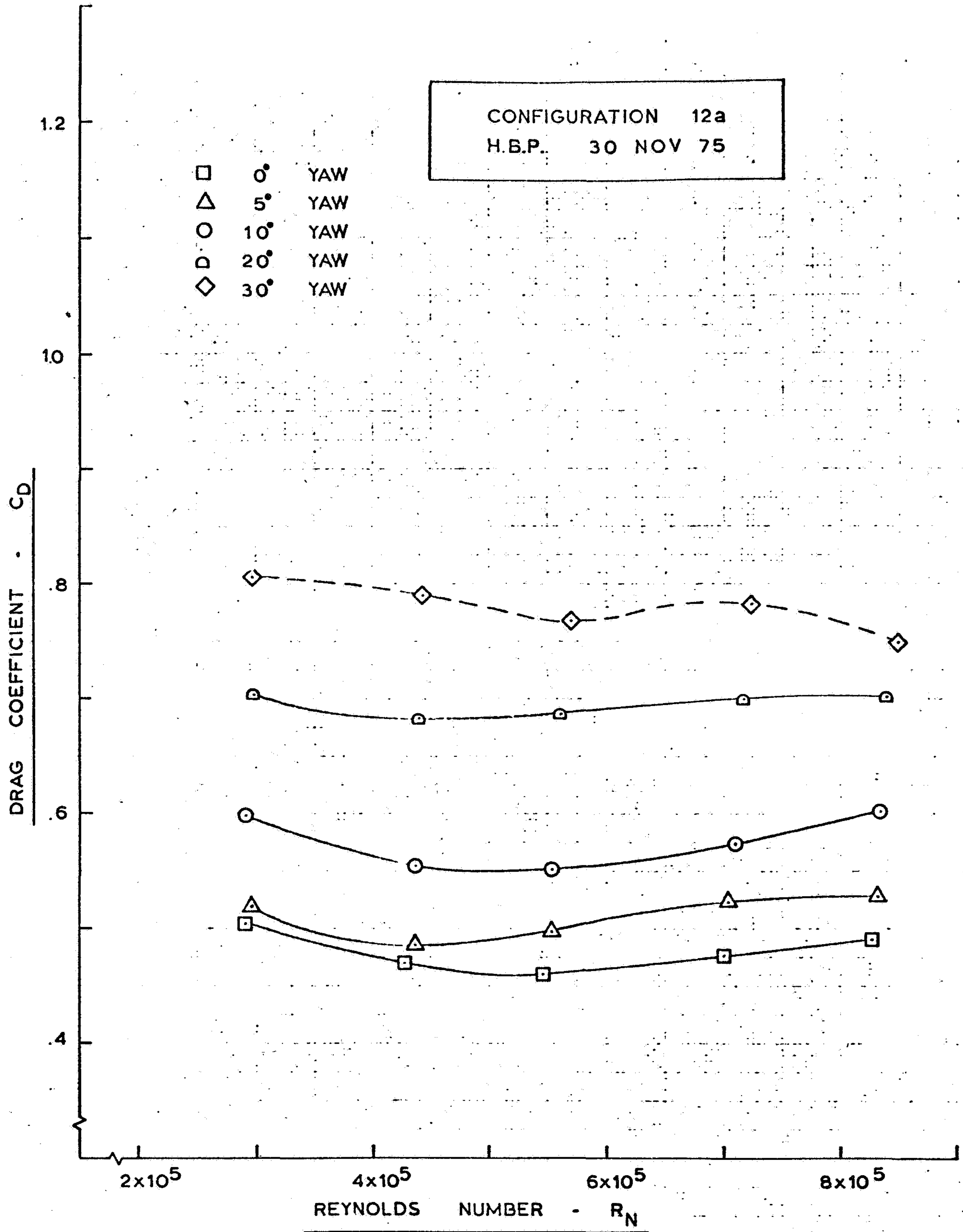


Figure 13. Effect of Reynolds number on drag coefficient-Configuration 12a.

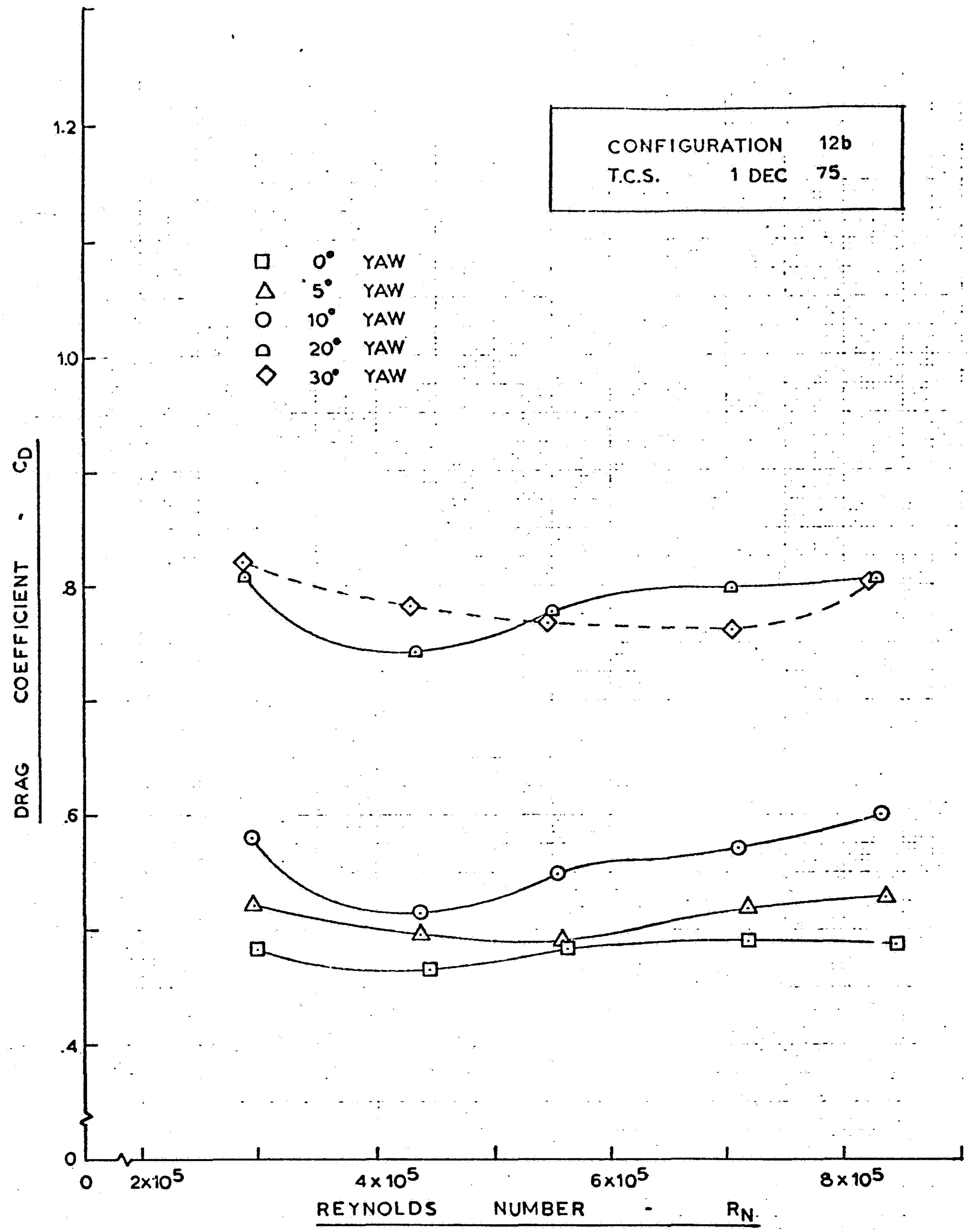


Figure 14. Effect of Reynolds number on drag coefficient-Configuration 12b.

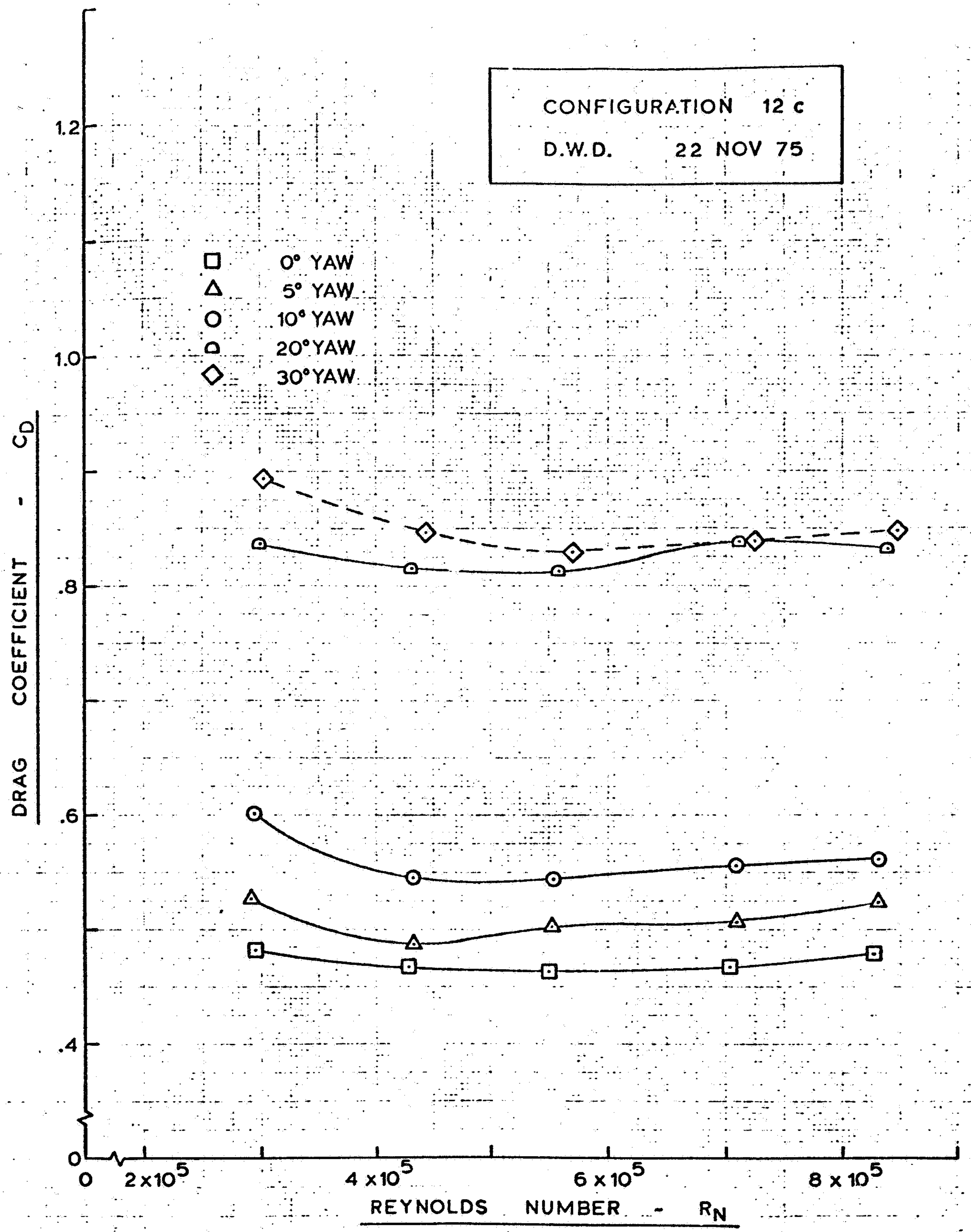


Figure 15. Effect of Reynolds number on drag coefficient-Configuration 12c.

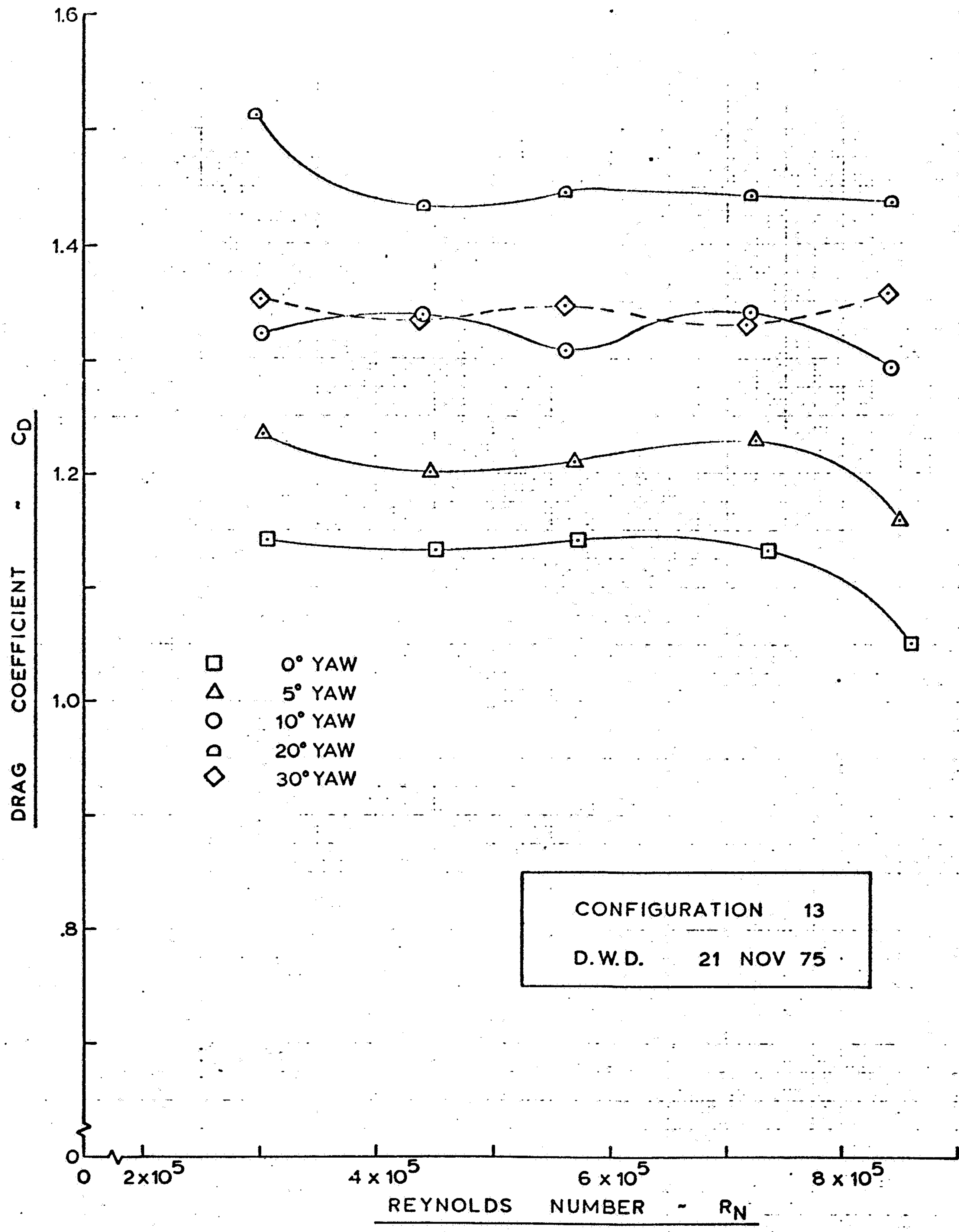


Figure 16. Effect of Reynolds number on drag coefficient-Configuration 13.

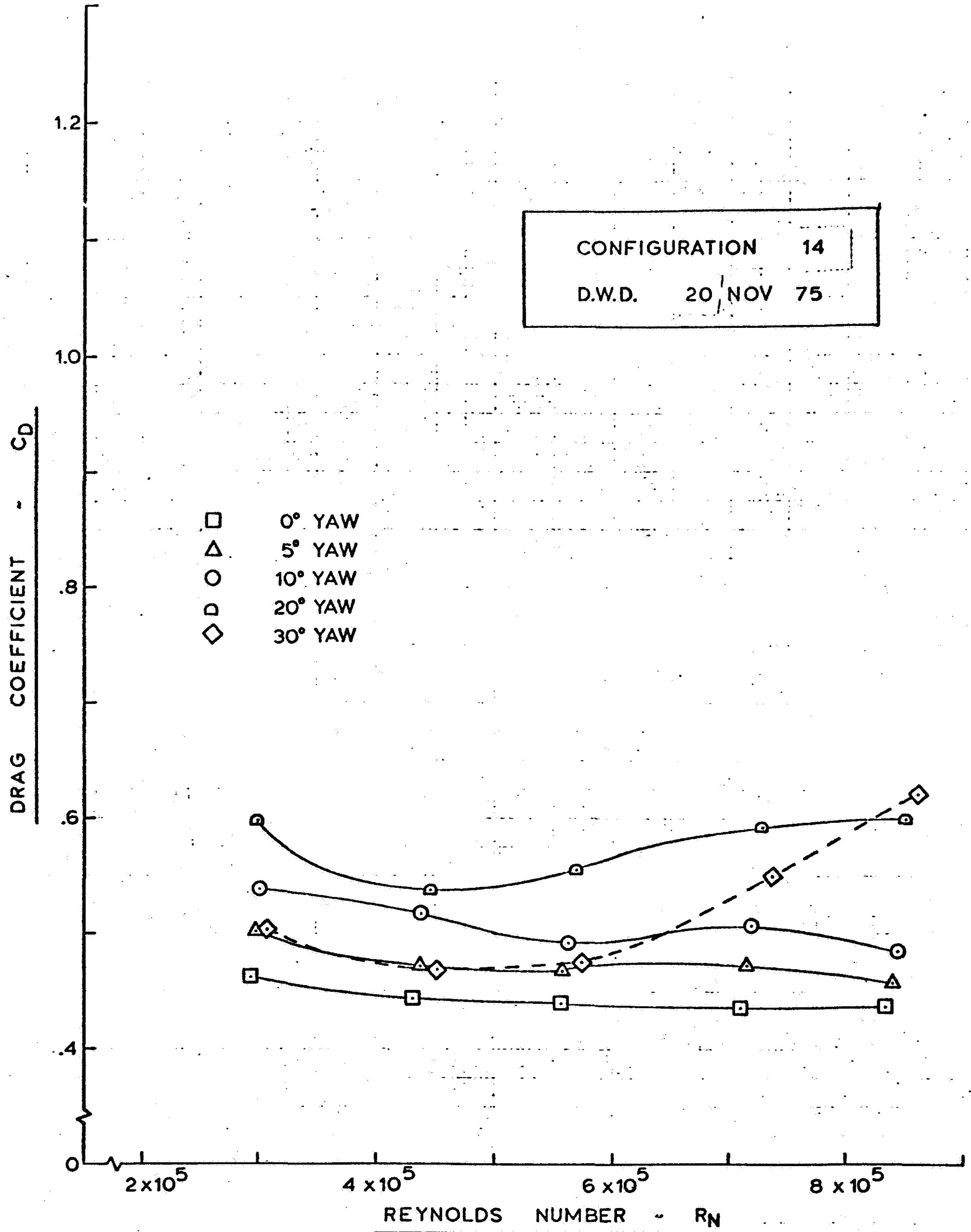


Figure 17. Effect of Reynolds number on drag coefficient-Configuration 14.

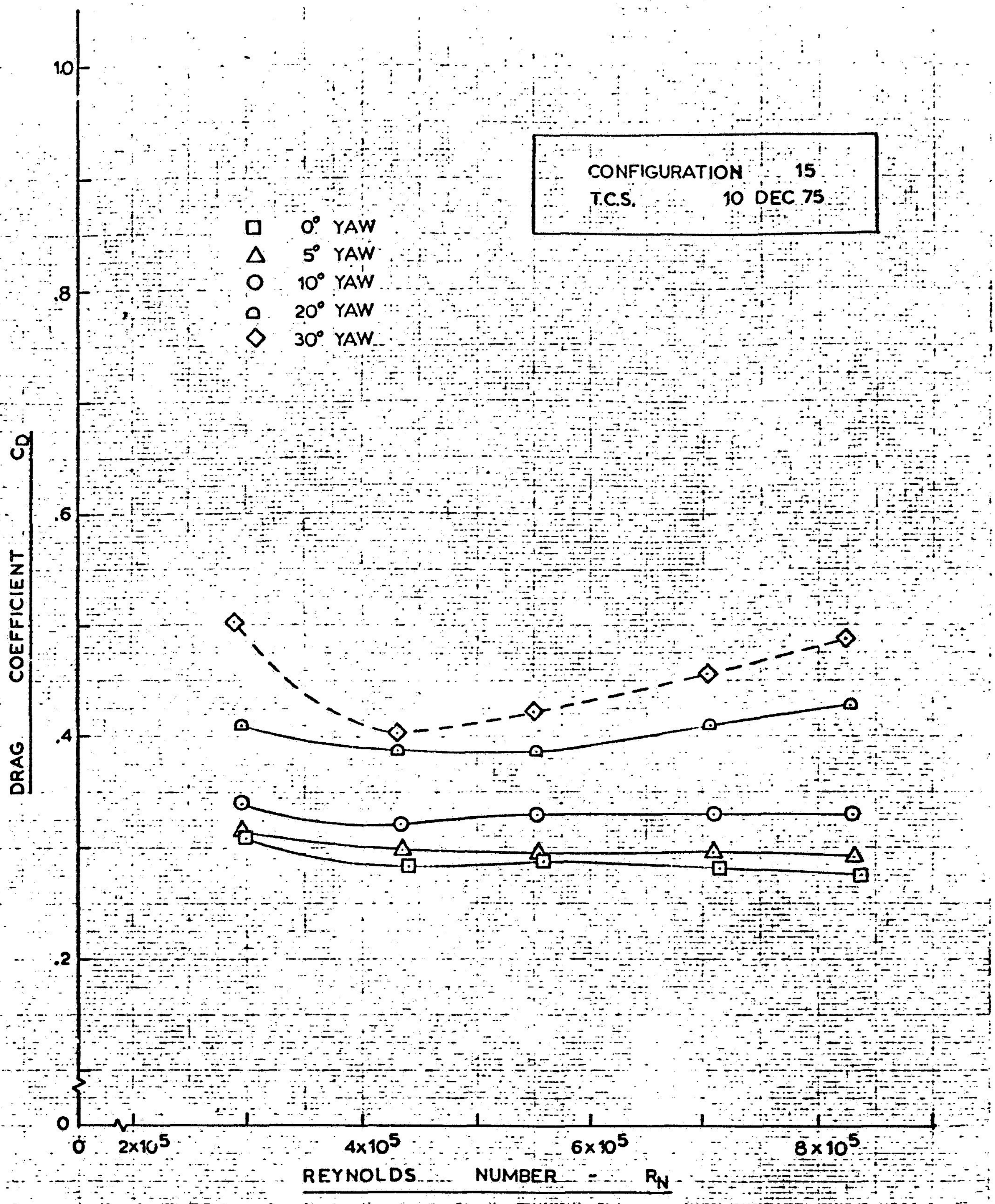


Figure 18. Effect of Reynolds number on drag coefficient-Configuration 15.

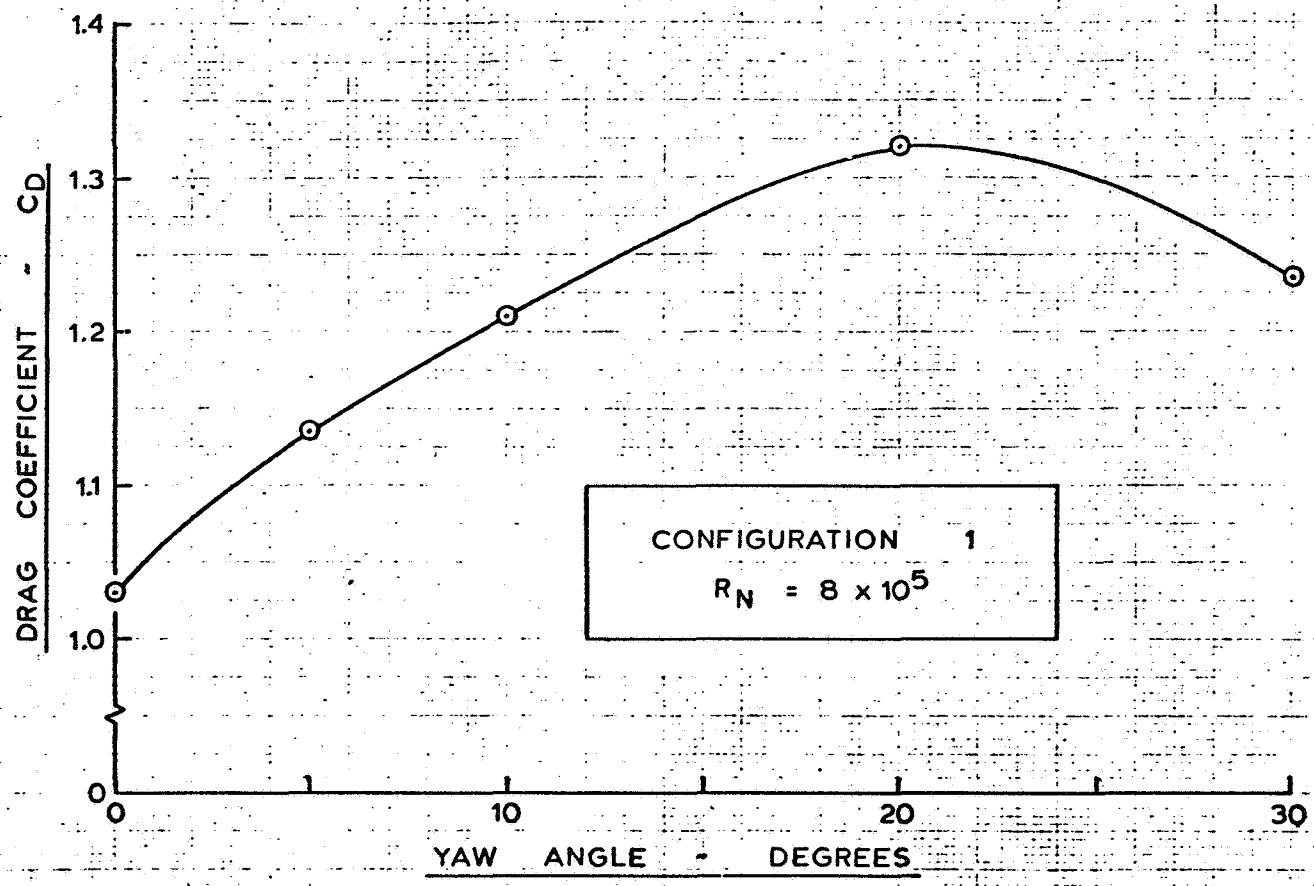


Figure 19. Effect of wind angle on drag coefficient-Configuration 1.

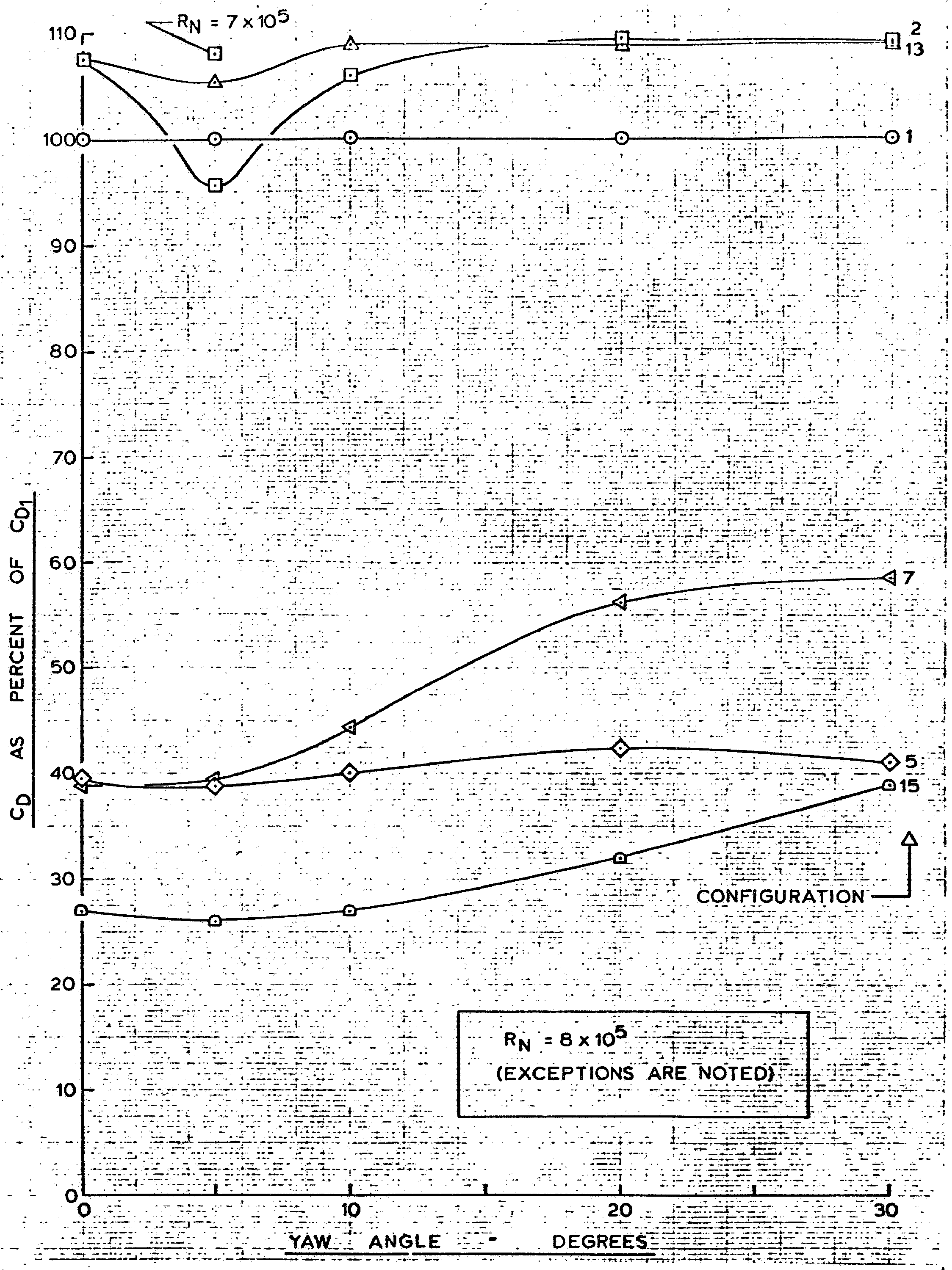


Figure 20. Comparison of drag coefficient-Configuration 1, 2, 13, 7, 5, 15.

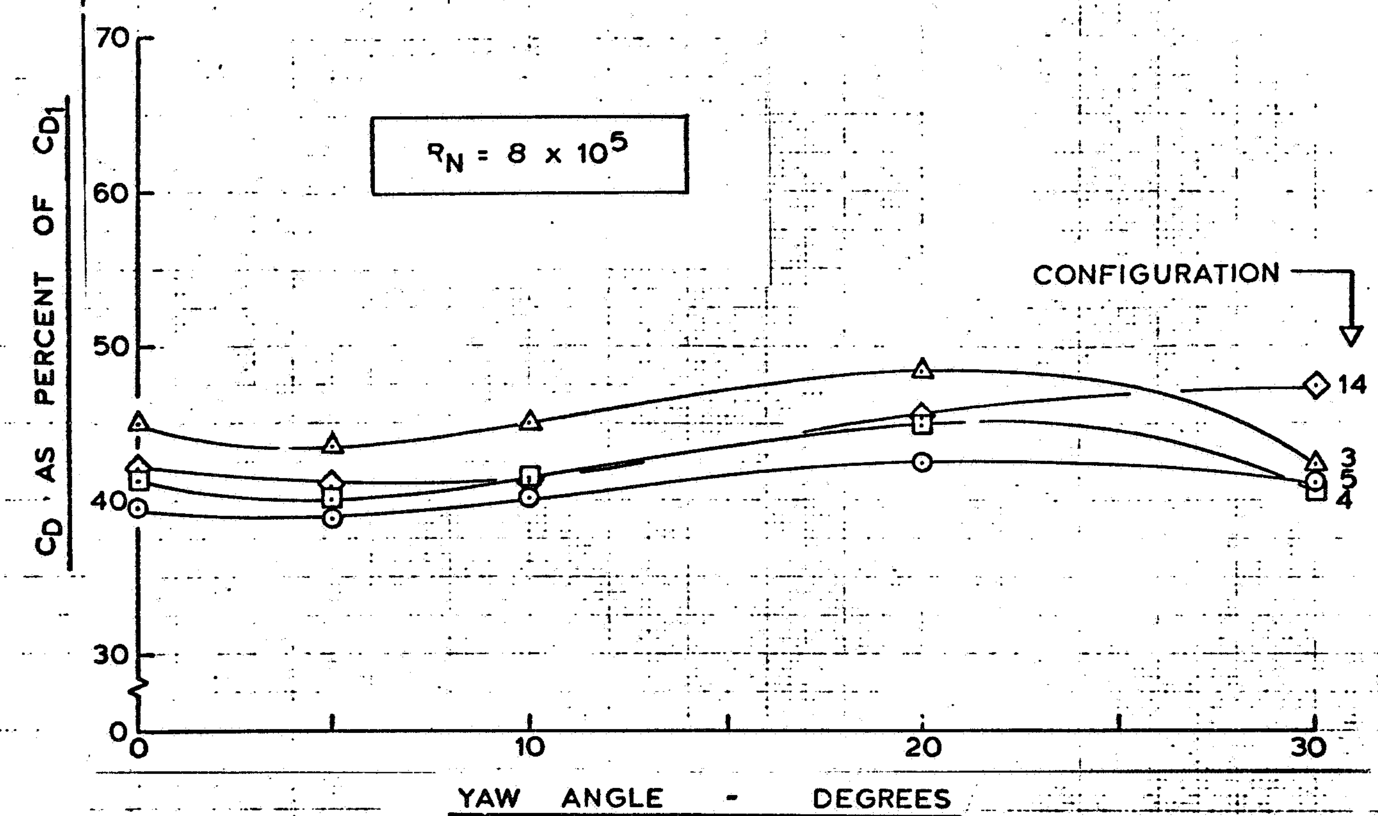


Figure 21. Comparison of drag coefficient-Configuration 5, 4, 14, 3.

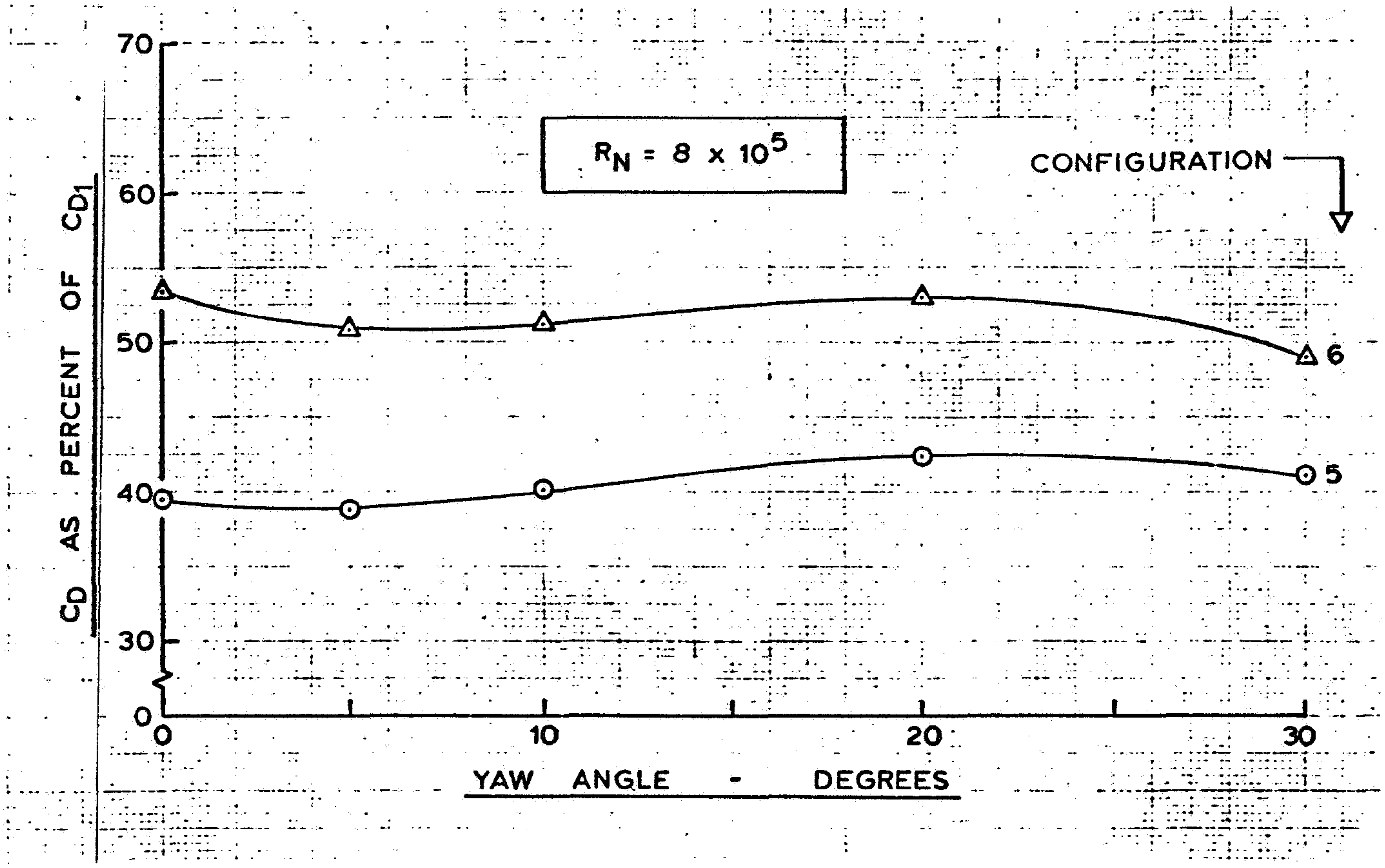


Figure 22. Comparison of drag coefficient-Configuration 5, 6.

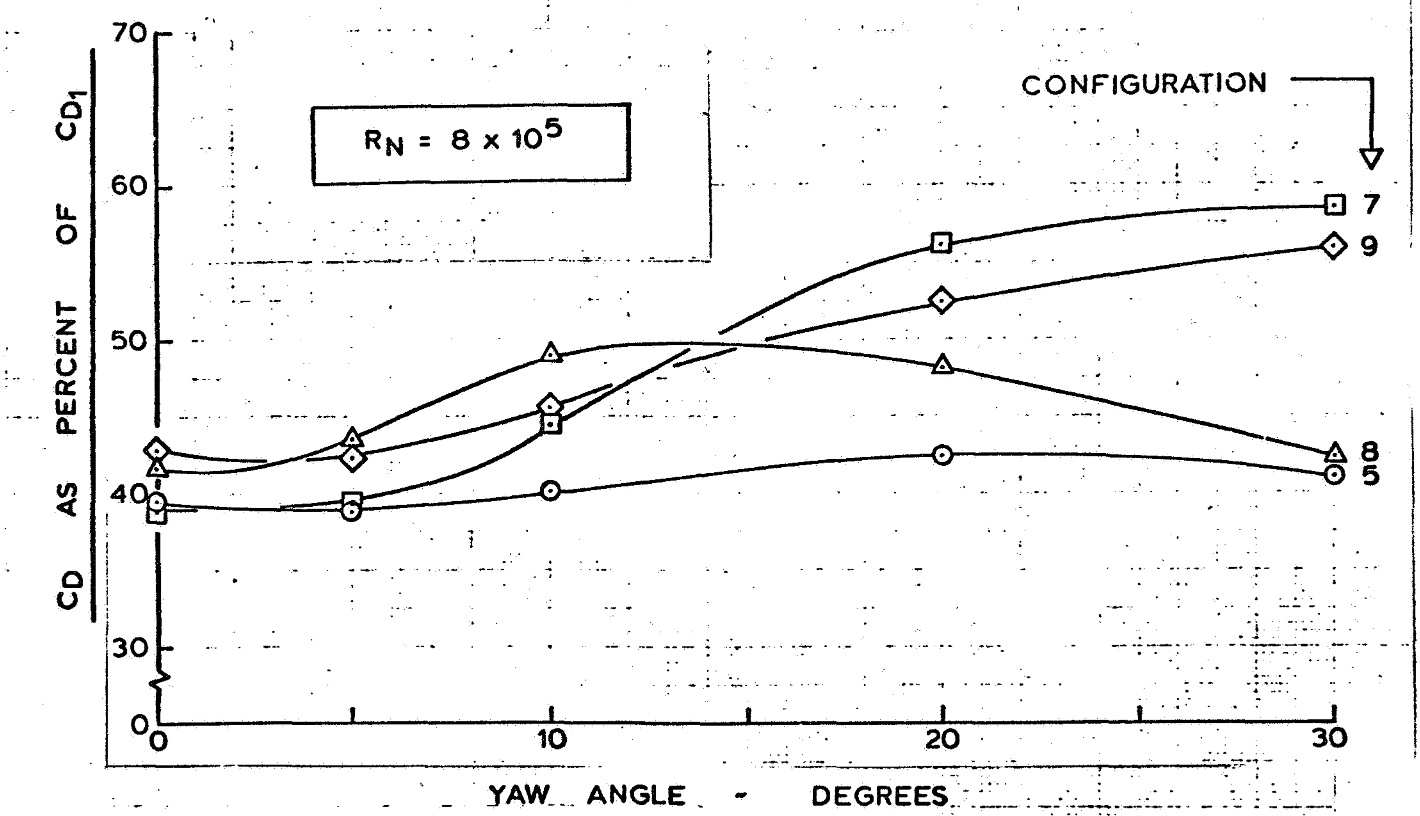


Figure 23. Comparison of drag coefficient-Configuration 5, 7, 8, 9.

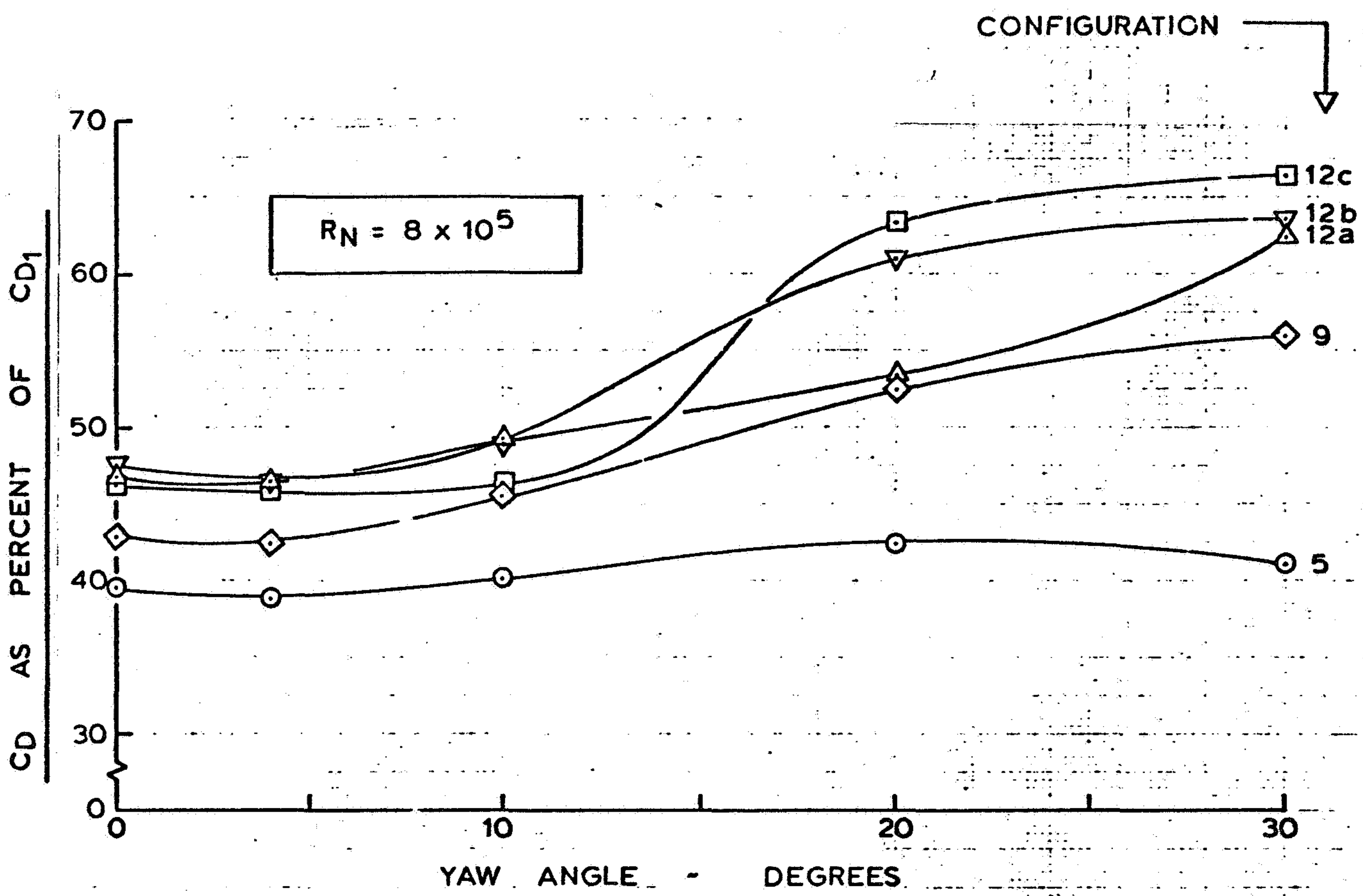


Figure 24. Comparison of drag coefficient-Configuration 5, 9, 12a, 12b, 12c.

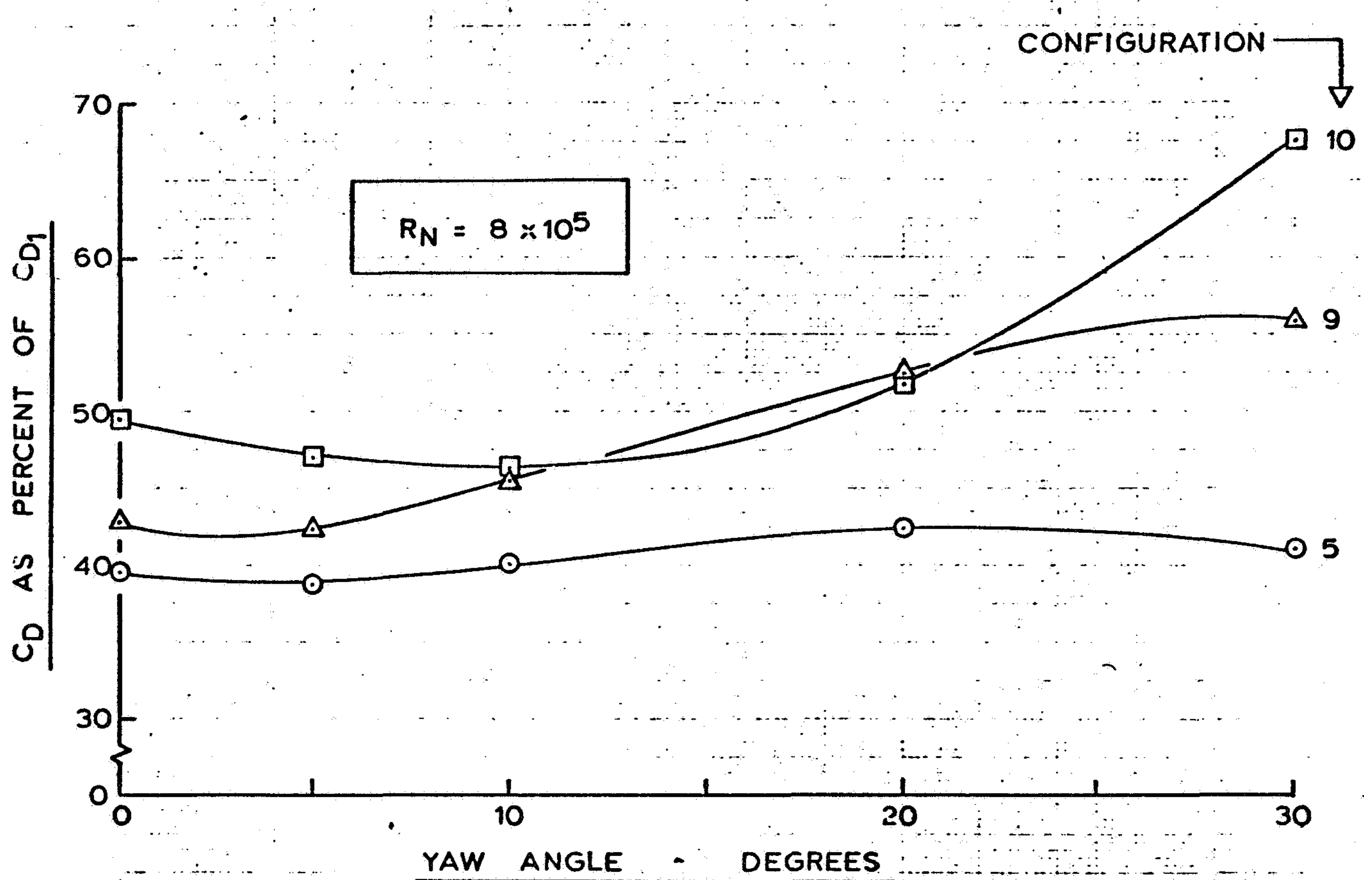


Figure 25. Comparison of drag coefficient-Configuration 5, 9, 10, 11.

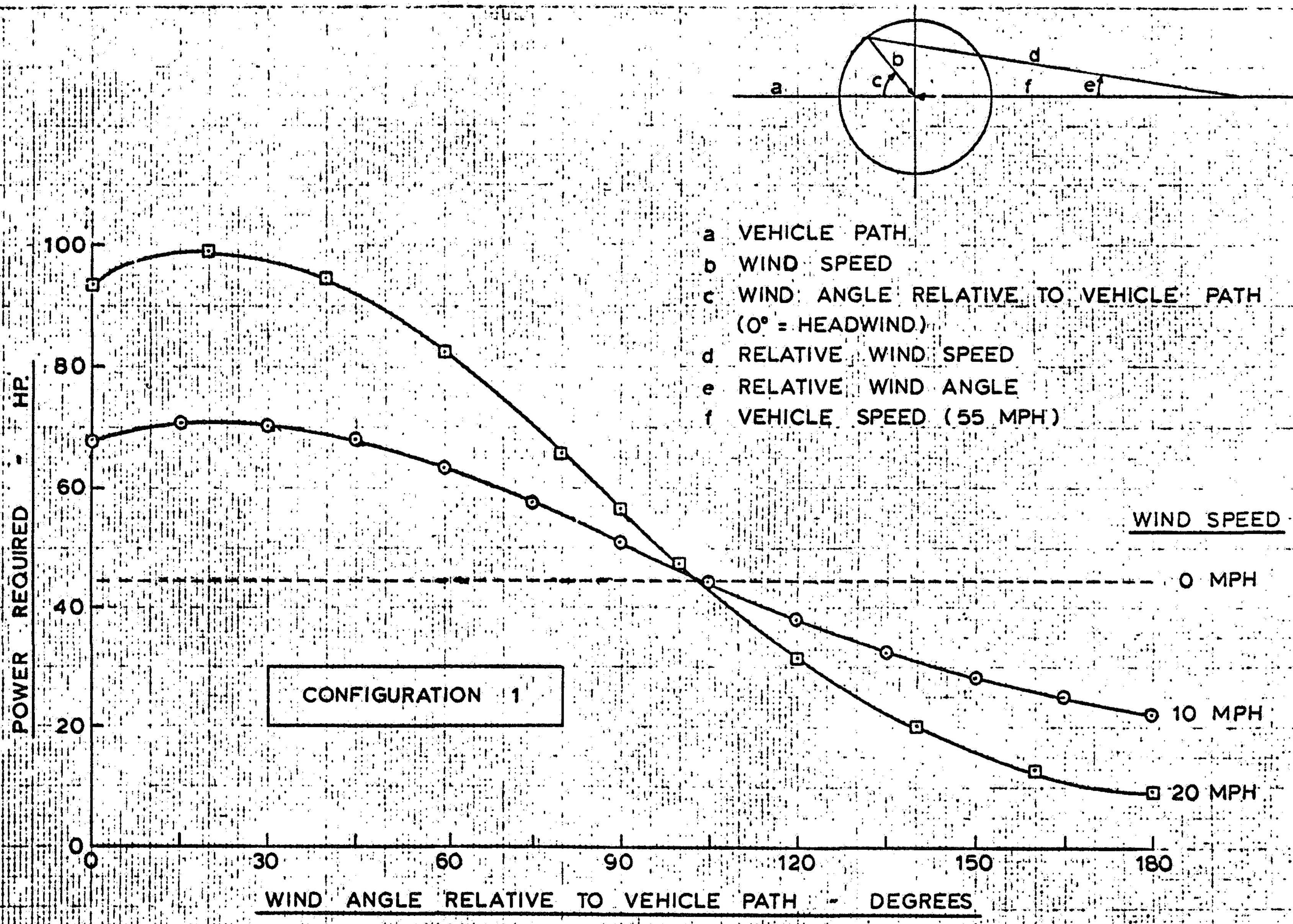
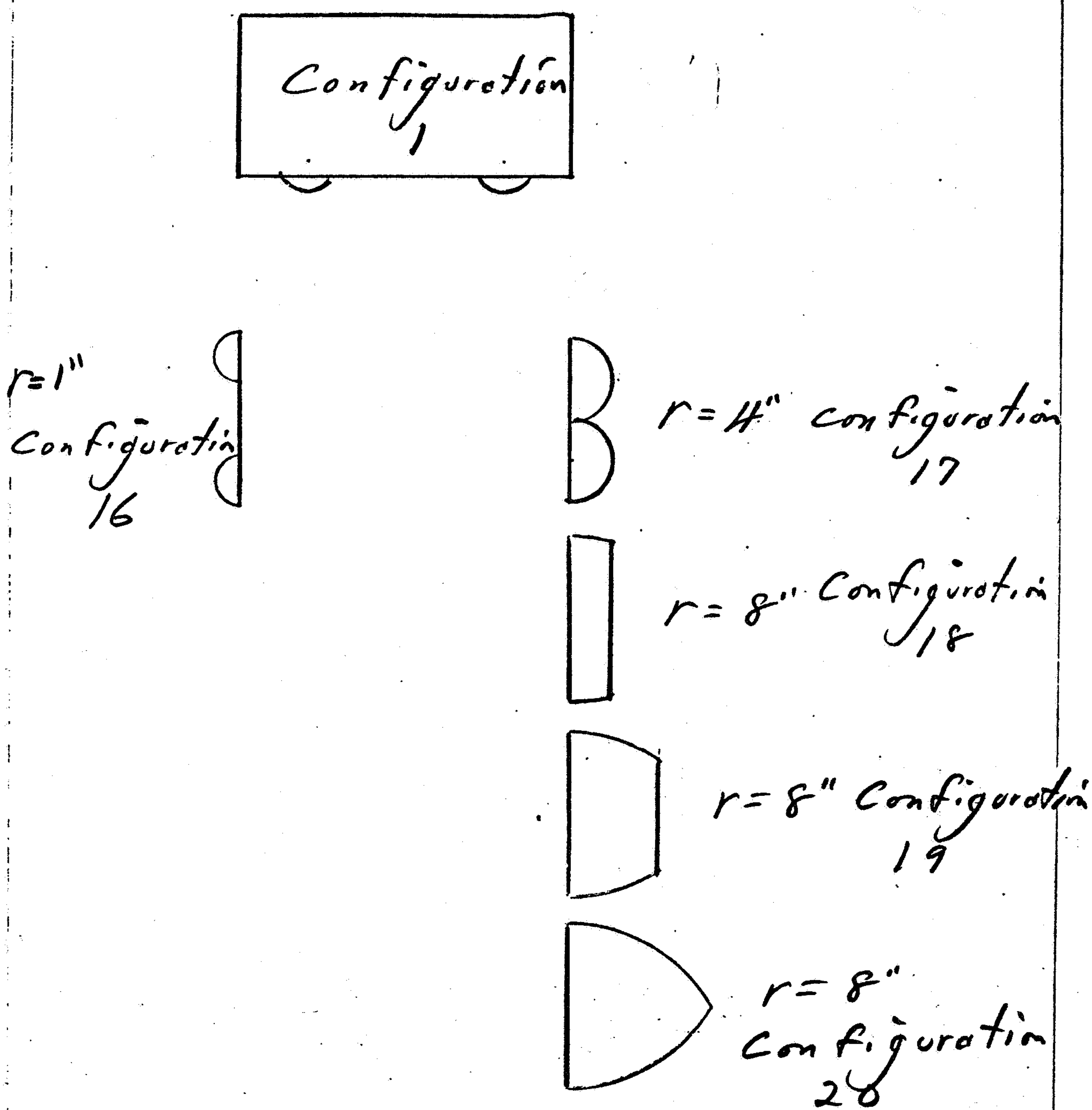


Figure 26. Power required for aerodynamic drag.



Configuration 21 - Configuration 6 with sealed bottom

Figure 27 Additional test configurations