July 18, 1967 R. K. WERNICKE 3,331,462

SURFACE EFFECT DEVICES WITH DYNAMIC BOUNDARY LAYER BLEED SLOTS

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Fig. 1.

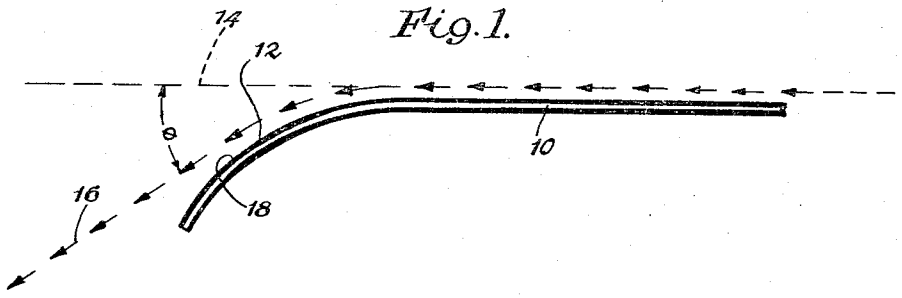


Fig. 2.

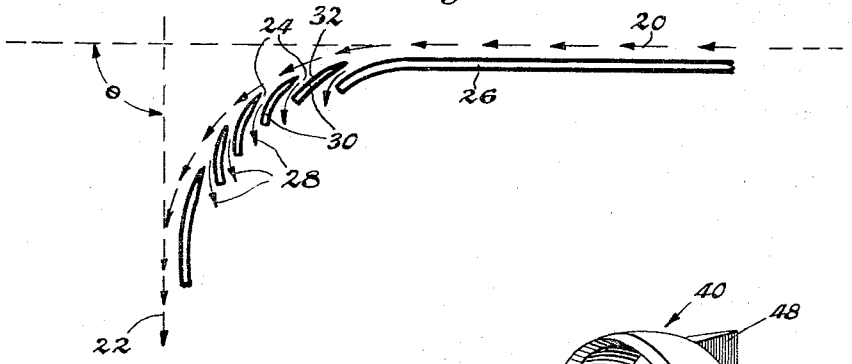
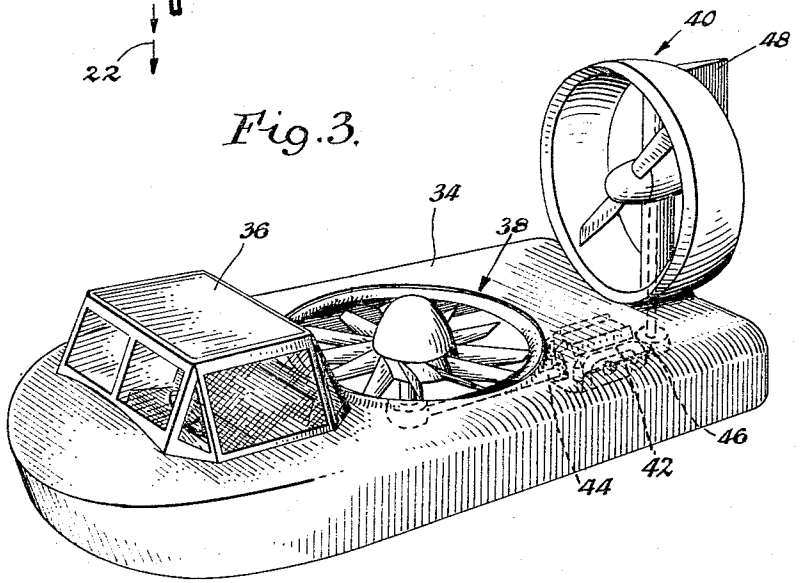


Fig. 3.



INVENTOR.
RODNEY K. WERNICKE

BY

Bean, Brooks, Buckley + Bean
ATTORNEYS

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Fig. 4.

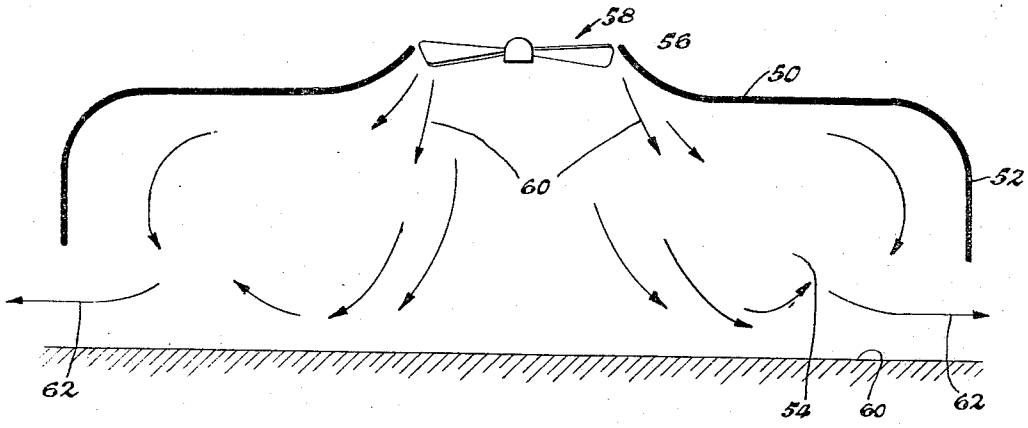


Fig. 5.

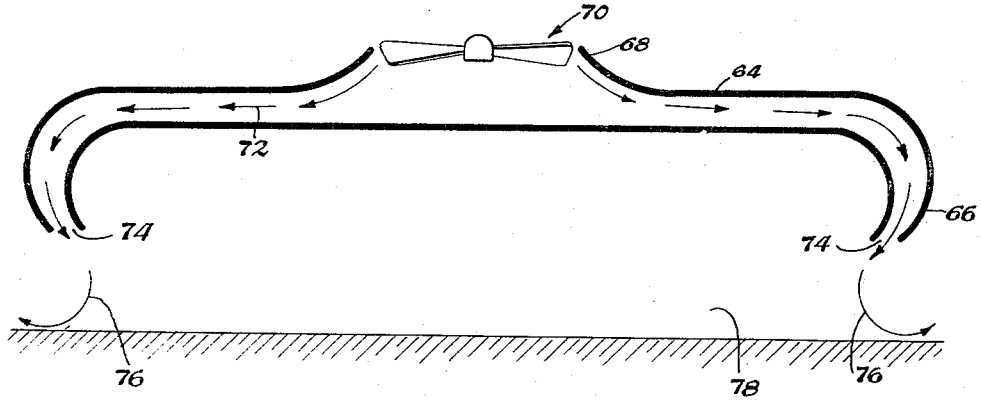
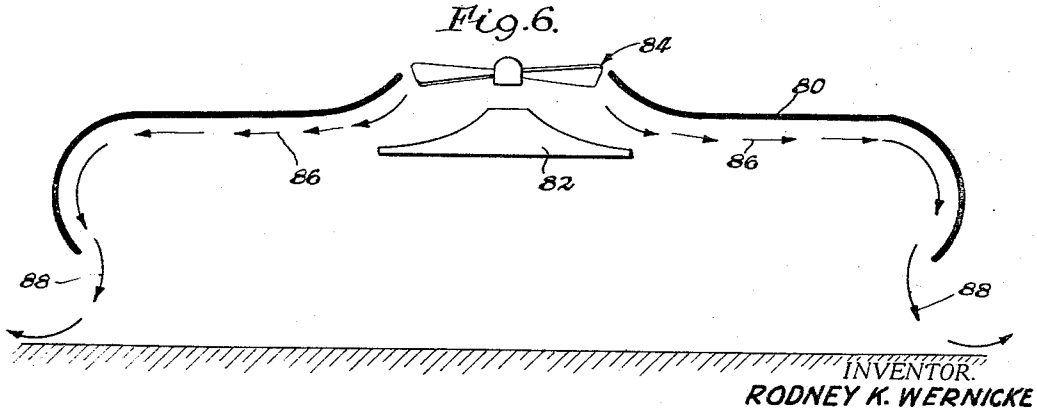


Fig. 6.



INVENTOR.
RODNEY K. WERNICKE

BY

Beau, Brooke, Buckley & Beau
ATTORNEYS

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Fig. 7.

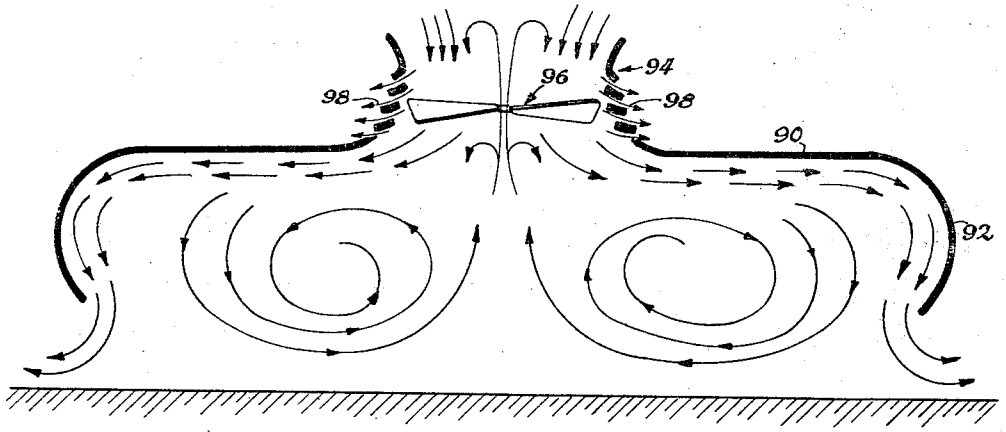
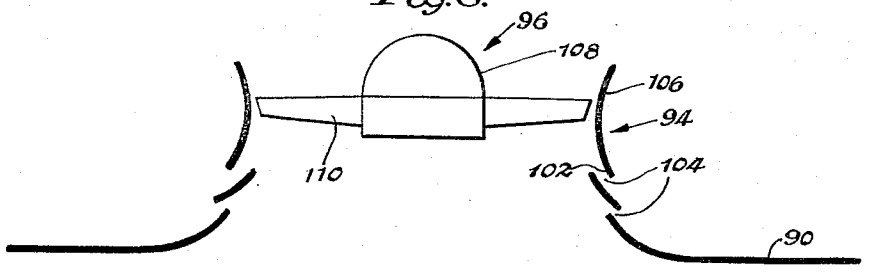


Fig. 8.



INVENTOR.
RODNEY K. WERNICKE

BY

Beau, Brooks, Buckley & Beau
ATTORNEYS

United States Patent Office 3,331,462 Patented July 18, 1967

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SURFACE EFFECT DEVICES WITH DYNAMIC BOUNDARY LAYER BLEED SLOTS

Rodney K. Wernicke, Hurst, Tex., assignor to Bell Aerospace Corporation, Wheatfield, N.Y.

Filed Jan. 25, 1965, Ser. No. 427,855
3 Claims. (Cl. 180—7)

ABSTRACT OF THE DISCLOSURE

Bleed openings in the body of a ground effect machine in regions of abrupt curvature thereof cause air flowing across the body to more closely follow its contours for ultimate discharge as a peripheral jet curtain of air.

This invention relates, in general, to an improved form of ground effect vehicle and pertains, in particularity, to a low silhouette vehicle employing the Coanda effect to produce a peripheral jet sheet discharge from a plenum chamber.

The Coanda effect is that characteristic of a mass of air moving over a convex surface to tend to follow the contour of such convex surface. Whereas this well known effect is capable of gradually altering the flow path of a so-moving mass of air, if the curvature of the convex surface is too abrupt, the moving mass of air will separate from the convex surface. Bearing this in mind, it will be appreciated that although the Coanda effect might be used to advantage in a ground effect machine of the plenum chamber type to achieve a peripheral jet sheet or curtain discharge of air without the aid of ducting and/or air deflection means, the height of such a machine would be prohibitive. The reason for this is that the air inlet opening for a ground effect machine will normally be of rather small dimensions as compared to the skirt of the machine, and if air is to be deviated, by the Coanda effect, from such inlet to a condition of peripheral jet curtain discharge at the skirt, the total deviation of the air would require a substantial vertical spacing of the air inlet above the skirt in order to achieve a sufficiently gradual slope from inlet to skirt. Thus, in a ground effect machine of the type described, it would be of material advantage to enhance the Coanda effect so that a moving mass of air may be deflected at a greater rate than would normally be possible to attain, and so permit the machine to be of low silhouette. It is, therefore, of primary concern in connection with the present invention to provide means whereby the Coanda effect is materially enhanced so that a moving mass of air may be deflected or altered in its path of movement to a substantial angle much greater than was heretofore considered possible.

Essentially, the present invention is directed to the provision of air bleed openings or slots in a convex surface over which a mass of air is moving whereby the Coanda effect is materially enhanced so that much greater angles of deviation of the flow path of a so-moving mass of air may be accomplished.

It is a further object of this invention to provide an improved structural combination in a ground effect vehicle whereby a plenum chamber type of construction may be employed to obtain a substantially peripheral jet sheet discharge for producing an enclosed, vehicle-supporting superatmospheric air cushion without the necessity for providing ducting means or impingement deflecting means to achieve such peripheral jet sheet discharge:

FIG. 1 is a somewhat diagrammatic view illustrating the well known Coanda effect;

FIG. 2 is a view similar to FIG. 1 but showing the utilization of air bleed slots or openings in accord with the present invention to achieve a much greater angle of deviation for the moving mass of air;

FIG. 3 is a perspective view showing a ground effect vehicle of the general type with which the principle of the present invention may be utilized;

FIG. 4 is a diagrammatic view illustrating the plenum chamber type of ground effect vehicle;

FIG. 5 is a diagrammatic view illustrating the peripheral jet type of ground effect vehicle;

FIG. 6 is a diagrammatic view illustrating a combined plenum chamber-peripheral jet type of ground effect machine;

FIG. 7 is a diagrammatic view illustrating the principles of the invention applied to a ground effect machine constructed in accordance with the present invention; and

FIG. 8 is a partial sectional view illustrating the construction of the entrance duct in accord with the present invention.

Referring at this time more particularly to FIG. 1, reference character **10** indicates the skin or wall of a body over which a mass of air is moving as indicated by the arrows. The wall **10** is shown as provided with a convex surface portion **12** and, as illustrated, as compared with the initial path of the mass of air as indicated by the dashed line **14**, a total deflection of the mass of air occurs along the direction of the dashed line **16** such that the mass of air is deflected to the angle θ as compared to its initial path. The phenomenon which produces this result is called the Coanda effect and is due to the tendency for a moving mass of air flowing over a surface to tend to follow the contour of such surface even though such contour is of convex form as is shown. This effect is old and well known and it is also well known that the angle cannot be made to be very substantial since the air will tend to separate from the convex surface **12**, as indicated for example at **18**, even though the convex curvature be made very smooth. Thus, in order to achieve any substantial angle of deviation, the convex curvature must be long and gradual. In accord with the present invention, the convex curvature may be made quite abrupt so that an angle θ up to and including angles of 90 degrees may be achieved in a relatively small space. The manner in which this is accomplished is illustrated in FIG. 2 of the drawing where it will be seen that the initial mass of air **20**, as indicated by the arrows, undergoes a total deflection or deviation, as indicated by the arrows **22**, which represents an angle θ of 90 degrees, and which is achieved very rapidly or, in other words, in a short distance. The manner in which this is accomplished is by enhancing the Coanda effect by providing openings such as those indicated by the reference character **24** in the surface of the wall or body member **26** within the confines of the convex surface thereof, substantially as is shown. These openings permit a small amount of the air to bleed through the wall **26**, as is indicated by the arrows **28** and the net effect is to cause a greater angle of deviation in a smaller space than was heretofore thought to be possible. Since the static pressure on that side of the wall **26** opposite the flow indicated by arrows **20** will be greater than on the flow side, openings **24** must be formed so as to cause the air bleeding therethrough to diffuse and, for this reason, the overlapping portions of the louvres **32** (FIG. 2) are divergent as shown. Thus, it will be appreciated that the bleed openings must be properly formed, i.e., they must effect diffusing of the boundary layer of air passing over the wall member. In this fashion, the increase in static pressure of the boundary layer due to deceleration caused by drag does not at some point overcome the Coanda effect, as is usual, but, instead, the boundary layer is sheared-off by the leading edges of the louvres **32** and the diffusing effect, as aforesaid, converts the remaining velocity energy of the sheared-off boundary layer mass to static pressure. Thus,

the flow of air is effected in the direction of the arrows 28 rather than in the opposite direction which would be the case were it not for the diffusing effect of the openings 24. In other words, the openings 24 must be shaped so as to diffuse the air passing through them since the static pressure is higher on the opposite side of the wall 26. It is preferred that this effect be achieved by spaced louvre elements which are convexly arcuate, as shown. The small amount of air bleeding through the openings 24 comes from the boundary layer air mass adjacent the wall 26 and the boundary layer is thereby prevented from thickening to such extent as to cause separation of the main air mass from the wall 26. Thus, the Coanda effect is enhanced without the necessity for providing a pump to produce a negative pressure on that side of the wall 26 opposite to the side over which the mass of air is moving.

In order to illustrate a novel ground effect machine according to this invention, reference is had at this time to FIG. 3. FIG. 3 illustrates a ground effect vehicle which will be seen to include a body or hull 34 provided with a suitable cabin or the like 36 containing the pilot's or navigator's controls and, as well, a lift fan assembly indicated generally by the reference character 38 and a propulsion fan assembly indicated generally by the reference character 40. Both of the fan assemblies 38 and 40 are preferably driven from a common power plant assembly 42, drive connections being effected through the drive shaft assemblies indicated at reference characters 44 and 46. The propulsion fan assembly 40 may have a vertically pivoted rudder 48 associated therewith and/or the fan assembly 40 may be swivelable for steering purposes. The particular type of machine illustrated and described in conjunction with FIG. 3 is for illustrative purposes only, it being apparent hereinafter that the present invention is generally applicable to various types and configurations of ground effect machines.

To appreciate the advantages and inherent functional characteristics of the present invention as applied to and in combination with a ground effect vehicle structure, reference is had at this time more particularly to FIGS. 4–6 inclusive which illustrate three different general types of ground effect vehicle principles of operation. In FIG. 4, the diagrammatic illustration of a ground effect vehicle shown therein incorporates a plenum chamber 50 which may be rectangular, circular, elliptical or other plan view shape and which is characterized by having a depending and circumferentially extending skirt 52 so that the plenum chamber 54 is defined by the body structure. The plenum chamber is provided with an entrance duct 56 within which is located a suitable fan device indicated by the reference character 58 and which is effective to induct air into the plenum chamber in generally downwardly fashion as is designated by the arrows 60, for example in FIG. 4. This type of ground effect vehicle is characterized by its relatively low weight inasmuch as very little hardware and structure is required to provide the aforementioned plenum chamber 54. However, this type of ground effect vehicle is also characterized by its inability to achieve any substantial degree of elevation above the supporting surface indicated by the reference character 60. The reason for this is that the plenum chamber type of machine merely forms a superatmospheric cushion of air within the chamber 54 which is sealed from escape only by the depending skirt portion 52. Therefore, as soon as this skirt 52 elevates above the supporting surface 60, air may escape peripherally outwardly from the skirt 52 as indicated by the arrows 62 in FIG. 4, and the machine will rise to an elevation only such that the air escape at 62 is insufficient to decrease the pressure of air within the chamber 54 below that required for sustaining the vehicle in elevated position.

The type of machine shown in FIG. 5 is called a peripheral jet ground effect machine and will be seen to include a body 64 having the depending and slightly inturned marginal skirt 66 and the entrance duct 68 provided with the associated fan means 70. In addition, the structure of this type of vehicle is provided with suitable ducting mechanism 72 which provides a continuous nozzle 74 peripherally of the margin of the vehicle so as to discharge a jet sheet or curtain of air as at 76 peripherally of the vehicle and preferably in a downwardly and inwardly inclined direction as is illustrated by the arrows. The advantage of this type of construction is that the peripherally extending sheet or curtain 76 forms a seal which tends to prevent the escape of the superatmospheric cushion of air built up by the curtain and operating within the chamber portion 78 and, as a result, a much greater degree of elevation for this type of machine may be obtained as compared to the plenum chamber type of mechanism illustrated diagrammatically in FIG. 4. However, the peripheral jet type of machine suffers the disadvantage of requiring a rather complex and weight penalizing ducting system, as for example the bottom pan 72 in FIG. 5, which results in increased costs and reduction of payload.

In order to at least partially overcome the weight and economic penalties associated with the peripheral jet machine shown in FIG. 5 and to incorporate some of the advantages of the plenum chamber machine shown in FIG. 4 while at the same time enabling the mechanism to obtain a reasonable elevation above the supporting or ground surface, a machine such as is shown in FIG. 6 may be utilized. In the modified machine of FIG. 6, which may be termed a combined plenum chamber-peripheral jet machine or modified plenum chamber machine, the body member or portion 80 is of shape and configuration generally as is shown in FIG. 5. However there is no direct counterpart for the pan member 72 in FIG. 5. Instead, the construction according to FIG. 6 utilizes an impingement deflection means 82 located directly beneath the fan assembly 84 which deflects and directs the air from the fan means 84 generally horizontally radially outwardly as indicated by the arrows 86 so that the mass of air tends to follow the contour of the inner surface of the body member 80 for ultimate deflection and discharge peripherally of the body 80 in the downwardly and inwardly inclined substantially continuous and peripheral jet sheet as indicated by the reference character 88. Thus, although a peripheral discharge in the form of a substantially continuous jet sheet or curtain 88 is effected similar to the jet sheet or curtain 76 of FIG. 5, the construction of embodiment of FIG. 6 is materially simpler than that of FIG. 5 and is less costly as well as of less weight so as to enable a greater payload to be carried.

The present invention, as can be seen in FIG. 7, is more closely akin to the FIG. 6 embodiment but differs therefrom in that the impingement deflecting means 82 is entirely replaced by the Coanda effect enhancing means previously described. That is to say, the body 90 as is shown in FIG. 7 is provided with a marginal skirt 92 and with an air entrance duct assembly indicated generally by reference character 94 as well as the fan means 96. However, in this case, the lower portion of the entrance duct assembly 94 is provided with air bleed openings of the type described hereinabove (24, in FIG. 2) for providing the air bleed as indicated by the arrows 98 such that the bulk of the air discharged downwardly by the fan means 96 is caused to flow along the inner surface of the body 90 in the manner illustrated by the arrows in FIG. 7 for ultimate discharge downwardly and inwardly from the marginal skirt 92 to achieve a peripheral jet sheet or curtain effect.

Without the relationship of the present invention, it would require a substantial vehicle height to achieve outward deflection of the air from the relatively small entrance or inlet mouth outwardly to reach the skirt margin. Obviously, a vehicle of substantial height is not desirable for many reasons. At the same time, it is desirable to obviate the use of ducting or air deflection means to achieve a peripheral curtain discharge, since such means not only represents additional weight detracting from the

payload, but such means also decreases the clearance within the confines of the skirt, a disadvantage on some types of terrain.

To more clearly illustrate the structural combination of the ground effect machine constructed in accordance with this invention, reference is had to FIG. 8. In this figure, it is to be noted that the entrance duct assembly **94** is provided with a lower portion **102** which flares outwardly and downwardly to merge smoothly with the airwardly facing wall portion **90** of the plenum chamber construction and that it is within this portion of the entrance duct assembly **94** that the openings **104** for air bleed are provided. The entrance duct assembly **94** also includes an upper portion **106** which is constructed relative to the lower portion and which contains the fan device **96** in closely spaced enclosing or embracing relationship to such fan device, substantially as is shown. The fan assembly is provided with a relatively large hub portion **108**, as compared with the cross-sectional area of the upper portion **106**, and the fan blades such as those indicated by the reference character **110** extend radially outwardly from such hub **108**. In this fashion, discharge of air from the fan mechanism **96** is substantially confined to a peripheral discharge. That is to say, the hub cooperates with the upper portion **106** of the air entrance duct assembly **94** so as to form an annular channel or passageway therewith.

From the above, it will be appreciated that in the environment of a body having a convex surface which curves smoothly through an angle of the order of 90 degrees, the Coanda effect may be materially enhanced therein by providing the air bleed openings or louvres as described hereinabove so as to cause air flowing along the surface of such body to more faithfully follow the contour thereof and over an extent achieving a greater total angular deviation of air flow in a short flow length than has heretofore been accomplished. In particular, such effect is useful and beneficial in combination with a ground effect vehicle such as is more specifically shown in FIGS. 7 and 8 herein.

Whereas only one form of the invention has been illustrated and described in detail hereinabove, it will be understood that various changes may be made therein without departing from the spirit of the invention or the scope of the following claims.

I claim:

1. A ground effect vehicle having a body providing an open bottom plenum chamber,

said plenum chamber being defined by a downwardly facing, generally horizontal wall portion having a marginally disposed depending skirt merging smoothly therewith, and by an entrance duct leading to and through said downwardly facing wall portion, in which the entrance duct is of relatively small area as compared to the area bounded by said skirt and is joined with said downwardly facing wall portion remote from said skirt,

said entrance duct having a downwardly and outwardly flared lower portion merging smoothly with said downwardly facing wall portion and rising upwardly therefrom, and having a constricted upper portion joined with said lower portion to be positioned above the level of said downwardly facing wall portion,

fan means disposed within the upper portion of said entrance duct and being bounded in closely spaced relation thereby so that air is discharged substantially peripherally downwardly from the fan means in close adjacency to the inner surface of the upper portion of said entrance duct,

said lower portion of the entrance duct being provided with bleed openings therethrough constraining discharged air flowing adjacent the inner surface of said upper portion of the entrance duct to spread downwardly and outwardly to follow the inner surface of said lower portion for discharge therefrom in close and following relation to said downwardly facing wall portion for ultimate discharge predominantly peripherally downwardly from said plenum chamber at said margin thereof defined by said skirt.

2. The ground effect vehicle as defined in claim **1** wherein said fan means includes a hub of substantial area as compared to the area of said upper portion of the entrance duct, a plurality of blades projecting radially from said hub, and said hub being positioned centrally of said upper portion of the entrance duct to define an annular air discharge channel therewith.

3. A ground effect vehicle according to claim **1** wherein said bleed openings are defined in part by curvilinear louvre members projecting angularly from said lower portion of the entrance duct away from the air flow surface thereof.

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A. HARRY LEVY, *Primary Examiner.*