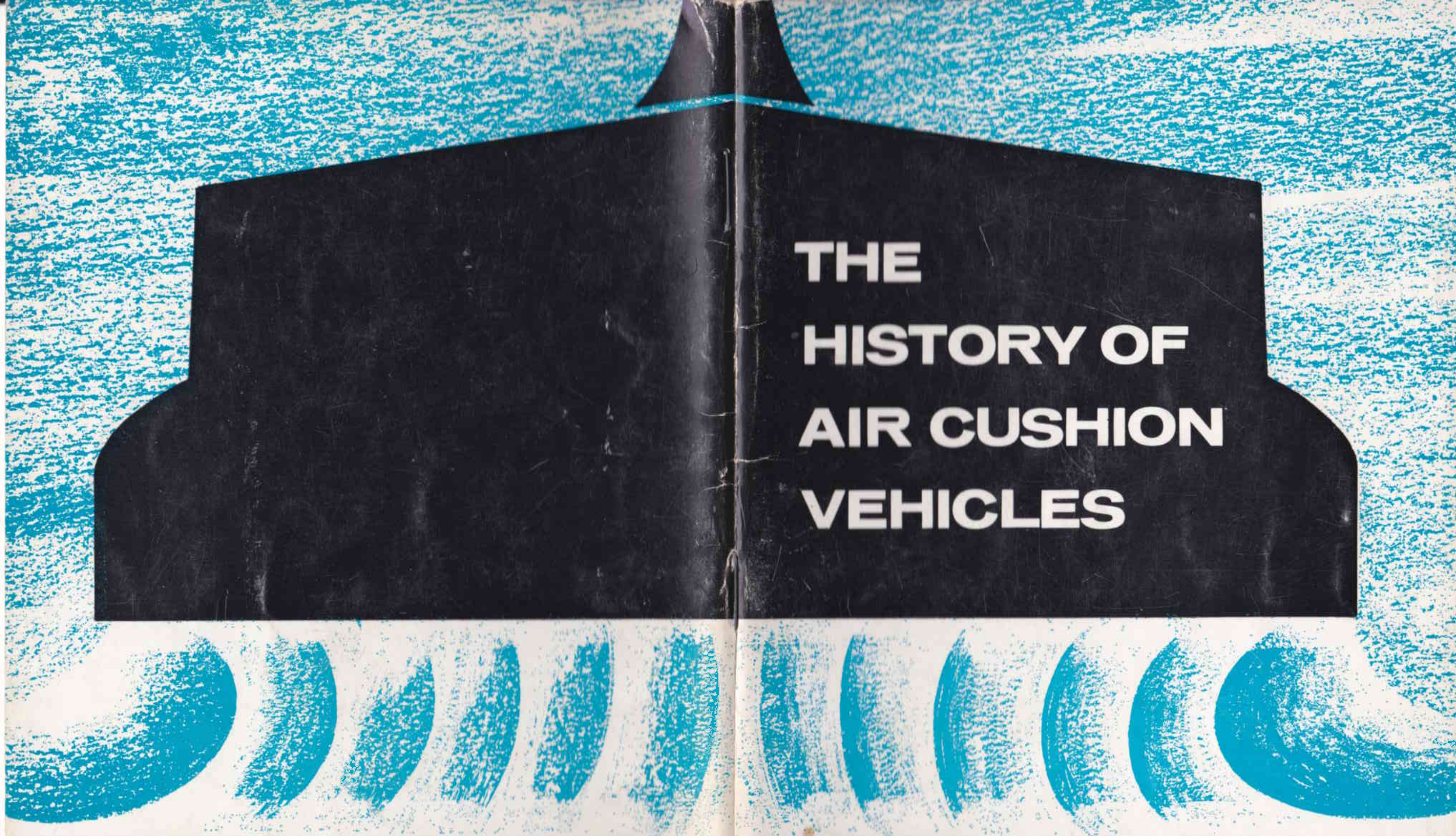

THE HISTORY OF AIR CUSHION VEHICLES

LESLIE HAYWARD

ATHĒNĒ

KALERGHI-McLEAVY PUBLICATIONS

Kalerghi-McLeavy Publications,
(Publishers of Hovering Craft and Hydrofoil)
53-55 Beak Street, London, W.1

First published 1963

Printed at the Press of Villiers Publications Ltd.,
Ingestre Road, London, N.W.5

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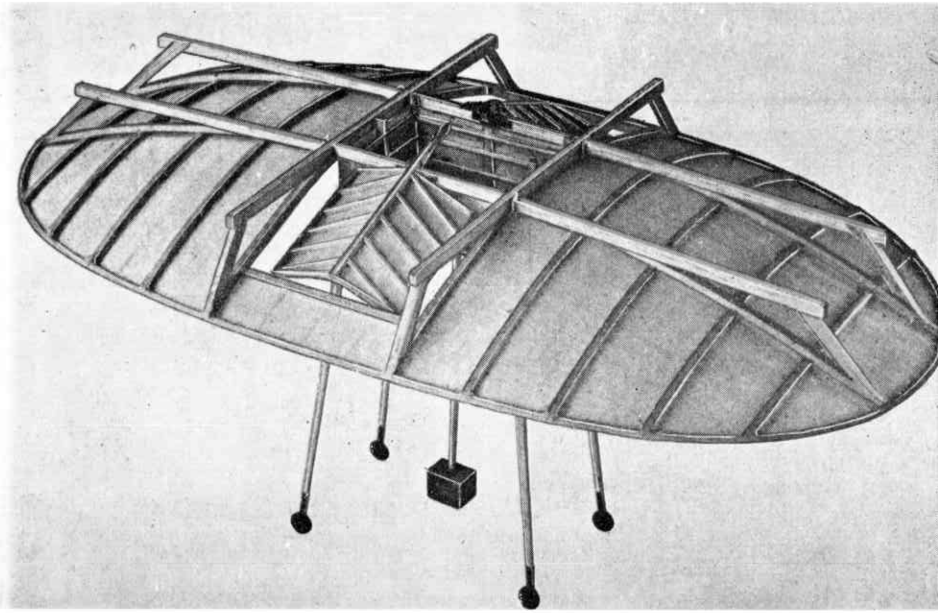
Leslie Hayward

Kalerghi-McLeavy Publications

Leslie H. Hayward was born in Bristol in 1918, and his interest in aeronautics started in 1931 when he won the Royal Empire Society (Bristol Branch) Essay Competition "A Journey by Air to Australia". In 1934 he was apprenticed to the Engine Division of the Bristol Aeroplane Co. Ltd. where he remained until 1939. From 1939 until 1945 he was engaged on engine development and technical publications on the staff of D. Napier & Son Ltd. From 1945 to 1950 he was assistant to the Patent Engineer of the Bristol Aeroplane Co. Ltd., and from 1950 to 1953 he worked as Patents and Commercial Engineer of Fairey Aviation Ltd. In 1951 he obtained the International Cierva Memorial Award. Since 1954 he has been Group Patents Manager, Westland Aircraft Co. Ltd. His previous publications include *The History of the Helicopter* and *Jet Propulsion of Helicopters.* In 1962 he became the fifth British recipient of the Bronze Medal of the Swedish Society of Aeronautics.



This dome-shaped machine was proposed by Emanuel Swedenborg, the Swedish scientist, in 1716

EVERY history of aeronautics of which I am aware starts off with regular monotony, with some vague references to Greek mythology, man's desire to fly, Leonardo da Vinci's inventions concerning gliders, ornithopters, helicopters, etc., Mongolfier, the Wright Brothers and Santos Dumont.

When ground effect machines are mentioned we can entirely dismiss these classical forerunners from our thoughts and it may be of interest to know that the first proposal which I can trace for a machine which today would fall under some classified heading, sub-heading or sub-sub-heading of ground effect machine was put forward by Emanuel Swedenborg, the Swedish scientist, philosopher and mystic during 1716. Swedenborg toured England, Holland, France and Germany between 1710 and 1715, and then studied natural science and engineering at Upsala university. His engineering interests varied from mining, transportation, metals, test tanks for ship models, machine guns, heating stoves and flying machines.

He proposed the machine shown at the head of page 3 during 1716. A domed, eliptical, light wooden frame is covered with canvas.

In the centre of the dome is an open cockpit. Apertures cut in the dome surface allow the blades of large manually operated "air oars" to pass air through to the underside of the dome. The oars move on a horizontal axis and are designed so that resistance to the upstroke is small, the downstroke compressing air and forcing it beneath the machine. From writings of Swedenborg it is obvious that he knew the machine would not fly but he appears to have been confident that the problem of flight would one day be solved. He is reputed to have said: "It seems easier to talk of such a machine than to put it into actuality, for it requires greater force and less weight than exists in a human body. The science of mechanics might perhaps suggest a means, namely, a strong spiral spring. If these advantages and requisites are observed, perhaps in time to come someone might know how better to utilize our sketch and cause some addition to be made so as to accomplish that which we can only suggest. Yet there are sufficient proofs and examples from nature that such flights can take place without danger, although when the first trials are made you may have to pay for the experience, and not mind losing an arm or leg '.

The illustration, shown by courtesy of the Director of the Stockholm Technical Museum, is a photograph of a model made to Swedenborg's design.

One hundred and sixty years later John B. Ward of San Francisco, California, proposed a machine provided with two supporting and one steering wheel. His power

plant could be made of aluminium and coupled to the two rear wheels for driving the machine along the ground. Rotary fans direct air in both downward and horizontal directions. To elevate the machine Ward used a series of blowers, each one being encased in the side of the machine, receiving air from side openings and discharging it vertically through openings in the base.

A large opening in the base houses a fan wheel that also operates as a gyroscope to maintain stability of the machine. Air entering the front of the large peripheral ducts passes through a rear mounted blower and exhausts through directionally controllable nozzles to provide forward movement and directional control. Ward stated: "In order to make use of the air to guide and sustain my machine when afloat I have constructed a plane, which may be quite large and is hinged or suitably supported so that its ends can be elevated or depressed by means of ropes".

Ward's proposals, seen in Figure 1, culminated in U.S. Patent 185465, granted on 19th December, 1876.

On 23rd May, 1877, Ward applied for a further U.S. Patent relating to detailed improvements for his machine. This patent was issued in October, 1877, as U.S. Patent 195860. The most important improvement suggested was coupling the peripheral air ducts to the central fan casing, and he also gives in the Patent Specification details concerning the construction of the variable angle fan blades and of the rear mounted blower.

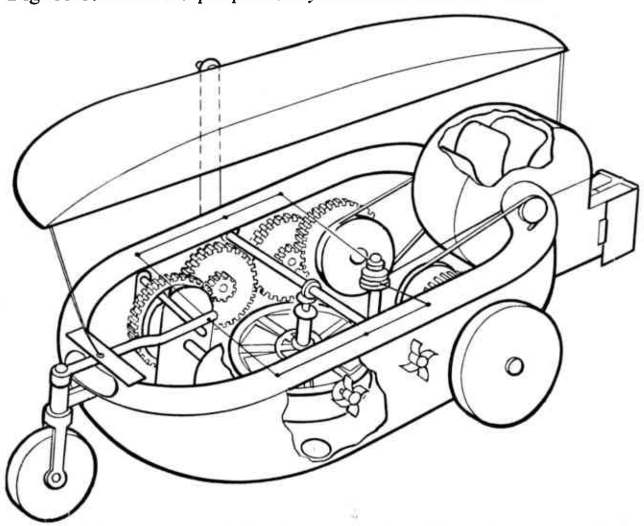
Before proceeding further with the general story I should like to arrive at definitions for various types of vehicle. Probably the best general definition that has emerged so far is:

An air cushion vehicle, at least in one stage of its operation, derives the major proportion of its support from a cushion of air, at above atmospheric pressure. The cushion of air is forced between the base of the vehicle and the surface over which it is operating. The vehicle can operate on land, water or in the air. Air cushion vehicles may be classified as follows (Figures 2 & 3):

The Ram Wing

This vehicle utilizes a normal type of aircraft wing structure adapted to be operated close to the ground or water. Forward propulsion is provided by propellers or jets and the forward motion of the wing in close proximity to the ground causes air to be trapped beneath it and the ground or water to form a cushion of air on which the vehicle rides. Lift is not obtained from a downward change of momentum of the air stream as in orthodox fixed wing aircraft. In some ram wing vehicles an air cushion can be created beneath the vehicle enabling it to hover as required or before directional flight is achieved.

Figure 1. *Machine proposed by John B. Ward in 1876*



Both helicopter and fixed wing aircraft make use of the ground cushion effect during certain conditions of flight and it has been reported on many occasions that during

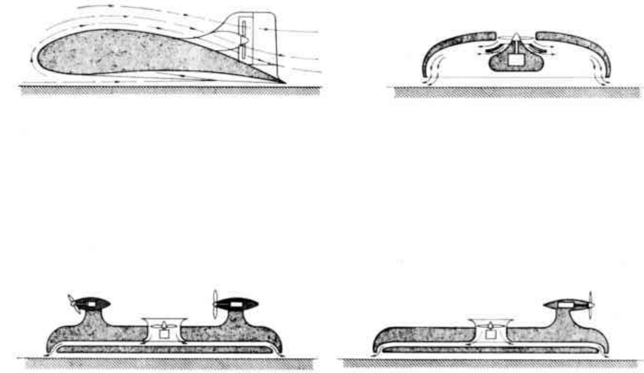
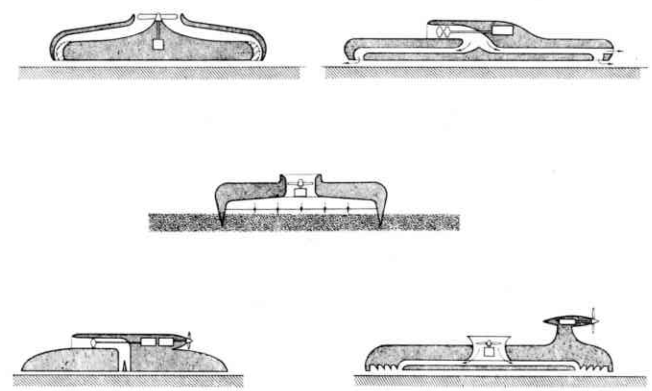


Figure 2. *Top left, ram wing; top right, plenum chamber, and beneath, annular jets*

Figure 3. *Top, annular jet control arrangements; centre, side-wall ACV; bottom, left, Levapad; right, Labyrinth seal*



1931 the Dornier Do. X twelve-engined flying boat crossed the Atlantic entirely within the ground cushion.

Plenum Chamber

The plenum chamber type of vehicle has the underside of its hull or body formed as a chamber or cavity and air is drawn from the atmosphere and pumped into the chamber to form an air cushion by an engine-driven fan. The machine is sustained on the air cushion at a height related to the leak rate of air from around the base edge. Suitable control and propulsion systems such as reaction jets or propellers can be incorporated and used with or independent from the main air supply. Flexible skirts or curtains used around the periphery of the machine will substantially increase its operational height.

Annular Jets

This vehicle is similar in form to the plenum chamber type, but instead of the air being pumped into a chamber it is forced through ducting which terminates in an annular orifice around the base periphery of the vehicle. The air cushion can be formed from and maintained by air leaving the annular jet. High pressure air thus forms a "curtain" or wall of air which encloses a cushion of air at a lower pressure. Control and propulsion can be part of the main air system or may be accomplished by independent power units. For efficient operation of this type of vehicle it is necessary to have some form of radial stability jets, dividing the main cushion into a number of separate compartments. As an alternative to the annular orifice around the base of the vehicle variants of this type are provided with a large number of nozzles spaced around the base periphery. When operating over rivers or open sea, water may be picked up as required by some suitable device and conveyed to the fan intake where it is mixed with the air to increase the density of the air cushion.

Flexible skirts around the periphery will, as in the case of the plenum chamber vehicle, substantially increase operational height.

Mechanically operated restrictors may be incorporated in the annular jet orifice for both stability and control purposes. Two or more annular jets may be used.

Labyrinth Seal

This type of vehicle operates in the same manner as

those already described but in addition incorporates a large scale adaption of an old idea. Air under pressure

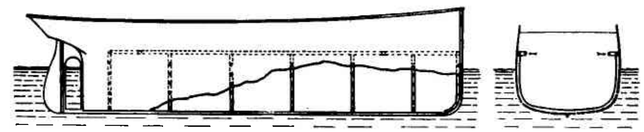
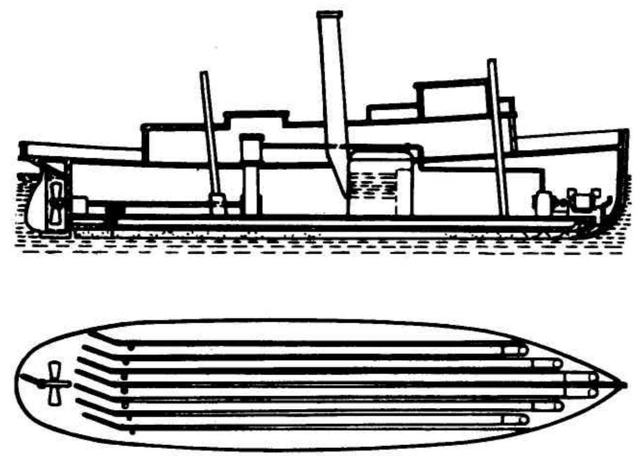


Figure 4. *Gustaf de Laval, the Swedish inventor, planned this air cushion boat in 1882.* Figure 5, *below, illustrates the next step forward, a proposal of Culbertson in 1897*



leaving the vehicle has to pass through a series of specially placed pockets or labyrinth seals, the effect being to progressively lower the pressure underneath the craft and allow air to escape with a calculated minimum loss to conserve power. Pumps or fans fitted in the pockets may be used to return air to the main air cushion and prevent excessive leakage.

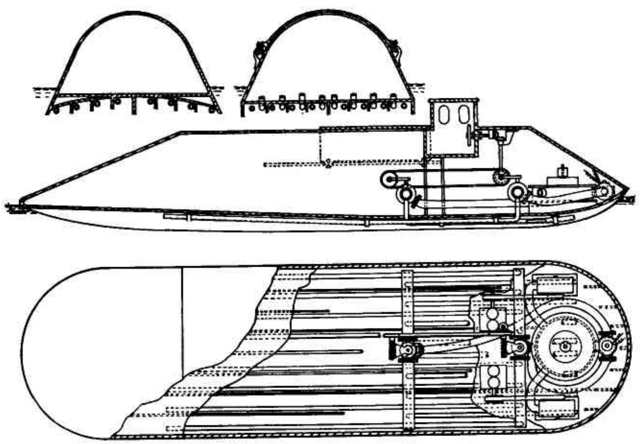


Figure 6. *A design patented in Britain by F. W. Schroeder in February, 1906*

Levapad

Vehicles and other moveable equipment such as load carrying platforms having substantially flat bases can be supported on a thin film of air supplied under pressure from single or multiple small discharge points in the base. These vehicles only operate over prepared level surfaces, the air acting as a lubricant which is continuously discharged from the periphery. In some instances a number of pads which are in themselves "Levapads" can be attached to the base of industrial machinery or equipment enabling the equipment to be easily moved. Further adaptations are for sliding railways and rail supported cars. This type of vehicle usually necessitates the use of an independent propulsion device.

Side Wall

Vehicles in this classification are limited to operation over water. The air cushion is created by an engine driven fan and is prevented from escaping along the length of

the vehicle by sidewalls or keels which at all times remain partially submerged in the water. Various types of adjustable flaps may be fitted between the side walls at the front and rear of the vehicle or alternatively air or water curtains may be incorporated. Propulsion may be attained by air or water propellers.

AIR CUSHION BOATS

Over the past hundred years attempts have been made by inventors all over the world to reduce the friction between water and various types of marine craft.

J. Scott Russell in his book *The Modern System of Naval Architecture,* 1865, Vol. 1, Page 109, talks of "a recurring proposal to lessen friction resistance is to pump air into the water ahead of, around, or under a ship". In a letter dated 23rd November, 1875, from William Fronde (British Admiralty) to B. J. Tideman, Chief Constructor of the Royal Netherlands Navy, it was proposed that the principle of air lubrication might be applied to ships with wide or circular plan form and the Russian ship *Popoffkas* was mentioned. This letter is now on display at the David Taylor Model Basin, Washington, D.C.

In 1882 the Swedish inventor, Gustaf de Laval, obtained British Patent 5841 for a ship having an air ducting system formed in or on the hull. (Fig. 4.) Air under pressure forced out of multi-jets in the tubes under the water line formed a continuous stream of air bubbles over the hull, on which it was hoped the ship would ride. A Swedish ship incorporating these proposals was built but experiments did not prove successful and development was discontinued. A book, *Speed and Power of Ships,* by Admiral D. W. Taylor, published in 1933, refers on Pages 33-34 to the Laval experiments.

American Patent 608757, of 1897 (Culbertson) illustrates the next step forward. (Fig. 5.) A ship's hull is provided with a number of longitudinal compartments open at the bottom and stern. Air compressors force air through the compartments so that the water has small frictional engagement with the hull. To assist in steering the craft, the air delivery ducts between the compressors and the compartments are lowered in the water and are rotated as desired. Auxiliary rudders form the rear portion of the compartment walls. In his patent specification Culbertson states: "Air will pass to the stern and will present a cushion intervening the hull and the water. Consequently the boat will move to a greater extent on sheets or cushions of air than on the water, although the water will engage with the auxiliary keels". One can look upon this disclosure as the father of present-day sidewall hovercraft.

From this time right up to the present day a very large number of proposals have been made and patents obtained for various forms of detailed designs of air lubricated boats.

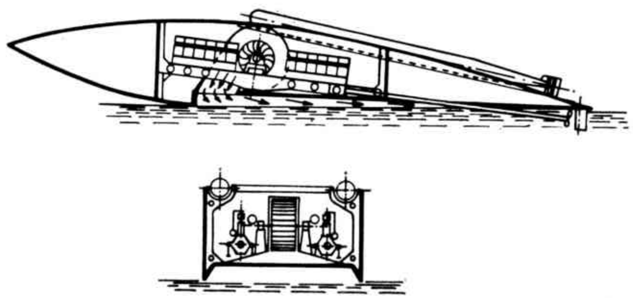
In 1888, James Walker, of Texas, was granted U.S. Patent 624271. The main design point was the provision of channels along the under side of the boat so that when rolling or pitching took place the air escaping from one channel was to some extent caught and retained by the channel immediately above it. British Patent 4231 of February, 1906, issued to F. W. Schroeder (Fig. 6) shows a design of a vessel operating on a layer of air between the water and the hull. Schroeder appears to have been aware of Laval's earlier experiments and states in the patent specification that his invention is the propulsion of a vessel "entirely effected by the escape of compressed air and gases acting against the surface of the water, so that the vessel practically slides or skates over the surface of the water and not through it". The drawings which accompany the specification show a broad bottom vessel having upwardly tapering front and rear and inwardly sloping sides. Air tubes having small exit holes all along their entire length are fitted to the underside of the vessel.

In 1916 Herr Dagobert Muller von Thomamhul designed and constructed for the Austrian Navy an air cushion torpedo-boat (Fig. 7). Four engines totalling 480 h.p. were provided for propulsion. It is known that tests were carried out on this craft and that it reached a speed of 40 sea miles per hour (Fig. 8). The photograph shown is believed to be the only pictorial record in existence of this machine and is shown by courtesy of the Austrian Technical Museum.

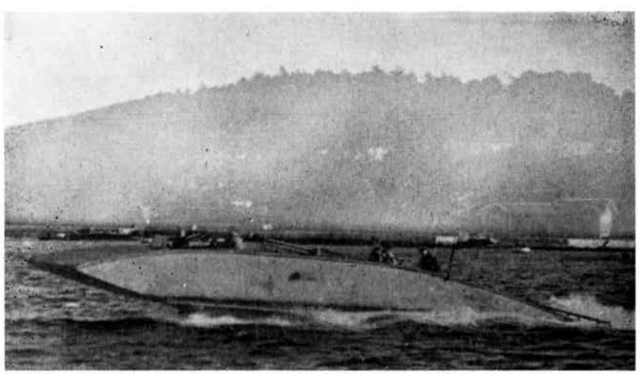
Towards the end of 1921, M. A. Gambin, a Frenchman, applied for a British Patent covering a large sidewall type of vehicle which he claimed could provide navigation on many impassable rivers, shallow waters and especially through waterways blocked by floating vegetation, etc. (Fig. 9).

Gambin's proposals appear to relate to a large barge type vehicle having any suitable form of power plant mounted in the centre of the craft. A drive shaft or a series of shafts are used to operate fans mounted in a ducted inlet at the bow, which is provided with special floats preventing the fan blades from striking the water when the craft pitches in rough seas. Air is drawn in and forced through fixed bladed ducting to a compression chamber formed between the underside of the machine and the water to create a gas cushion extending the length of vehicle. In order to obtain a good distribution of the air a series of notches or shoulders may be provided transversely across the underside. The sides of the vehicle are adapted to act as extended keels to prevent air from escaping. Although given British Patent No. 188648, Gambin's application was not completed and the patent became void.

In September, 1925, V. F. Casey, of Minneapolis, U.S.A., applied for U.S. Patent 1621625 which relates to an "Air floated barge" (Fig. 10). A large flat-bottomed vessel has a series of longitudinal air channels open at the underside against the water. Power-driven fans or blowers installed in the vessel discharge air in a rearward direction under the bottom of the vessel to sustain and propel it. Dividing the underside into a series of separate air channels greatly assists stability of the vessel. Air return pipes leading from the rear of the channels to the main and secondary blowers to boost the air supply, form a recirculating air system. This appears to be the first attempt at recirculating the air and thereby conserving engine power.



Figures 7 and 8. *An air cushion torpedo-boat designed and constructed in 1916 by Dagobert Muller von Thomamhul for the Austrian Navy. It attained a speed of 40 sea miles per hour*



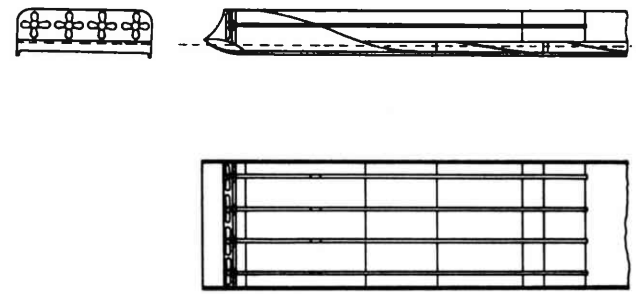


Figure 9. *In 1921 M. A. Gambin, a Frenchman, applied for a patent covering this design for a large sidewall craft*

In 1935 Jean Birrard, a French Naval Constructor, devised a system of air lubrication and obtained patents in both France and England. He transformed a boat (similar in shape to a hydroplane) 45.2 ft. long, 9.8 ft. beam and a draught of 1.05 ft., nominal displacement was 9.4 tons and capable of a speed of approximately 10 knots. The bottom of the vessel was divided into "compartments"

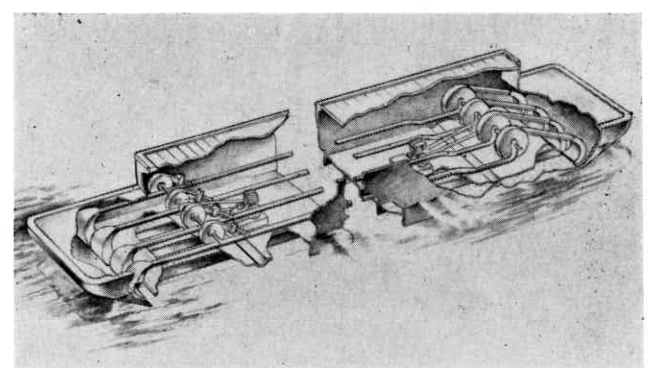


Figure 10. *In 1925 V. F. Casey, of Minneapolis, Minnesota, U.S.A., applied for a patent for this "air floated barge"*

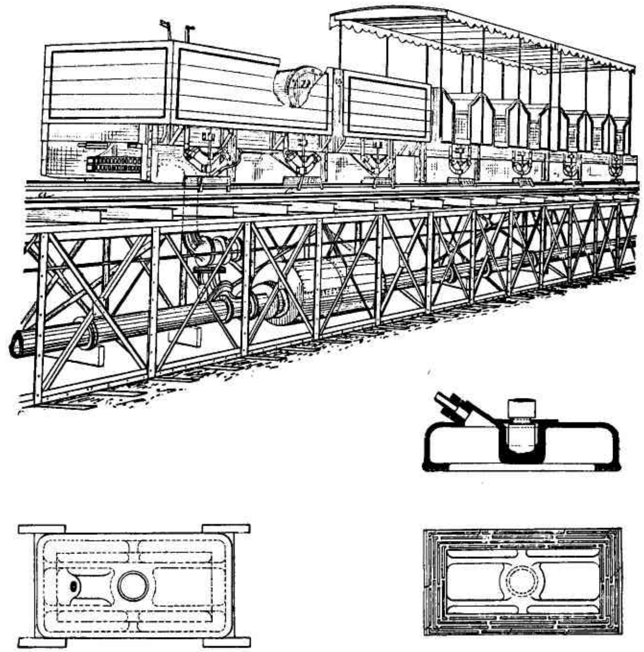


Figure 11. *General form of the railway developed by Louis Girard and Charles A. Barre in France in the 1880s*

by means of side keels and transverse deflectors. Compressed air was pumped out at the fore and deflected aft. The planes, which could be controlled from inside the vessel and set to "hydroplaning angles", were fitted at the fore end under the vessel. Birrard also considered that if the vessel ran aground, by pumping out air and forming an air cushion the boat could easily be refloated.

Many inventors have carried out research and development on air lubricated boats, the most prolific inventors being J. C. Hansen-Ellehammer of Denmark, C. J. Lake of the United States and Henry Clay of London. I am

aware of over 100 patents on this subject to date, and the illustrations used are typical of the more important developments over the last fifty years. Research is still being undertaken in many parts of the world, including the State Shipbuilding Establishment at Goteborg.

SLIDING RAILWAYS

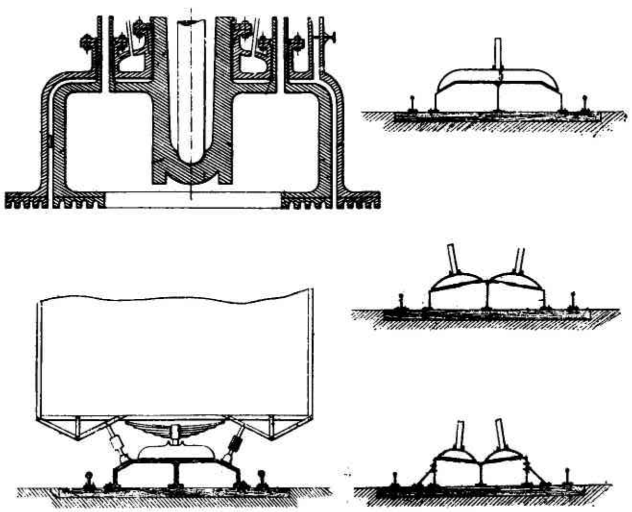
Both the technical and popular press have recently given prominence to a "new" proposal for hovertrains or sliding railways.

Early in 1880, a well known French engineer, Monsieur Louis Girard, who had done considerable work on turbine development, suggested a sliding railway in which the vehicles are supported by rectangular skids instead of the orthodox wheels. A thin film of water under pressure is interposed between the skids and the rails, and there is no point of contact between them when the vehicle is moving. The train is pushed forward by horizontal columns of water escaping from fixed jets placed on the rails at intervals. The water acts on specially designed orifices below the waggons; the first waggon opens the jets and the last waggon closes them so that the thrust action is only used as the train passes over them. These jets are connected to a pressure water conduit running the entire length of the track fed by a natural head of water. In a report published during 1888 it was stated that: "To transport a given useful weight, the sliding system requires a dead weight only a third of that required by a wheeled system". A small experimental railway was operated first in the park at Le Jonchere and later in the Esplanade des Invalides from the 12th July to the 6th November, 1889, and during this time covered a distance of approximately 900 miles. The train consisted of three coaches, and was approximately 50 ft. long. For winter operation, the installation was arranged so that the conduit water could pass through a steam engine surface condenser and was thus maintained at a required temperature.

Details of this work are given in the proceedings of the French Academy of Science during 1888/9. Detailed improvements were made by M. Charles A. Barre who worked with M. Girard during 1889/91 and these improvements are the subject of many French, British and other foreign patents. The British magazine *Railway News*, of 28th March, 1891, states that a "sliding railway" was demonstrated at the Crystal Palace, London, by Barre. The general form of the railway is shown in Fig. 11.

Further developments were proposed between 1902 and 1915 by another Frenchman, Charles Theryc. Obviously the consumption of water became an acute problem and

Figure 12. *Charles Theryc's proposal of 1909 was the first to suggest the use of air for a sliding railway*



Theryc proposed a number of devices which today are known as the labyrinth seal to prevent such a large loss of

water. (Fig. 12.) His British Patent 5569, of 1909, shows what he calls a cover slide fitted externally of the main slide and so constructed that water flows back to the reservoir in the train. He also states that using his device air may now be used to support the vehicle and I quote: "It was radically impossible with the Girard-Barre slide of 1889 as the loss of air was so considerable that such an arrangement would have been impossible". This is, then, the first proposal to use air for a sliding railway. Further proposals of Theryc relate to the form of slide, the manner in which the grooves are arranged, rubbing seals along the rail and the return of waste air to the compressor. In 1915 he obtained a number of patents on a type of edge pump, probably United States Patent 1152451 and British Patent 9011/1915 are the best examples (Fig. 13). The Specifications state: "The counter-pressure devices (i.e. edge pumps) will force beneath the grooves of the runner, the volume of air required in order to enclose and maintain within the interior of the runner, the cushion of compressed air at 1.8 kg. per sq. cm. The edge pumps may be driven by a wheel on the slide or by a wheel on an auxiliary rail and the train may be propelled by "engines working on propellers".

An American, Charles Worthington, also suggested during 1908 "a vehicle so constructed and combined with a conduit that it may be propelled and at the same time supported by compressed air; or if propelled by other means may be supported pneumatically. (Fig. 14.) An engine driving a propeller is also coupled to a compressor which supplies air through the base of the vehicle to form a pressure cushion beneath the large platform and the trough in which the vehicle runs. Sealing plates complete the pressure chamber. A somewhat similar proposal was made during January, 1913, by A. F. Eells, also an American.

In 1922 F. G. Trask, of N. Dakota, U.S.A., patented a sliding railway in which the air used to support the train is also used for propulsion purposes. (Fig. 15.) Discharge nozzles are associated with angled exits in the rail

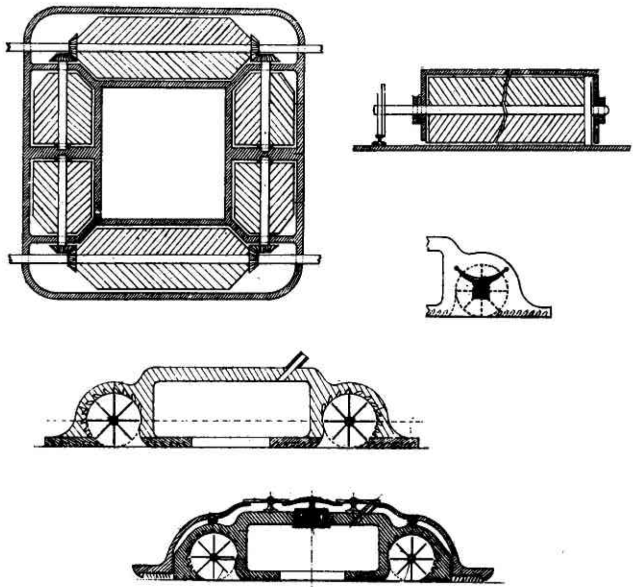


Figure 13. *Edge pumps designed by Theryc in 1915 to force air beneath the grooves of the runners of a sliding railway*

In January, 1907, an American, Joseph Clark, applied for U.S. Patent 989834 (Fig. 16). The drawing accompanying Clark's specification shows a machine which he describes as being capable of horizontal or vertical movements. A large forward facing air intake which can be collapsed or altered in attitude as desired, houses a large diameter fan driven by some form of powerplant, air passing through the fan is ducted along a conical annular duct and issues through the mouth of the duct in an annular system. A propeller is provided for forward motion and two large air ducts on each side of the intake converge

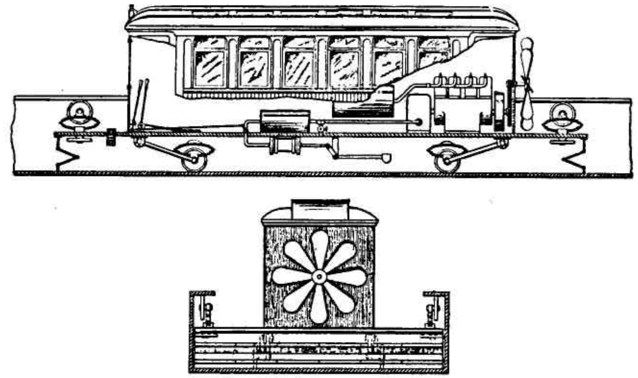


Figure 14. *An idea of 1908 for a train combined with a conduit and propelled and supported by compressed air*

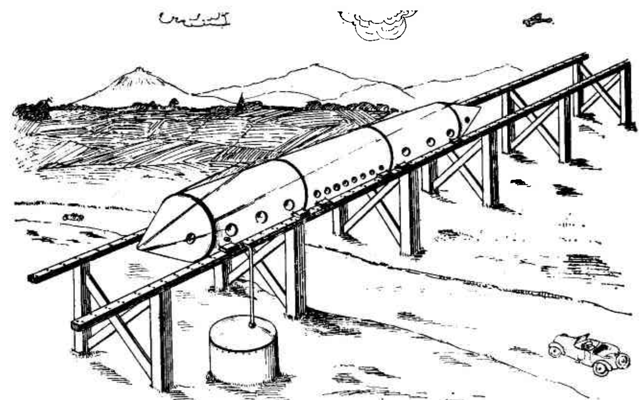


Figure 15. *F. G. Trask of North Dakota patented this idea for a sliding railway in 1922*

into a single duct at the rear. A plate valve is used for assisting directional control. This appcars to be the first design using annular ducts.

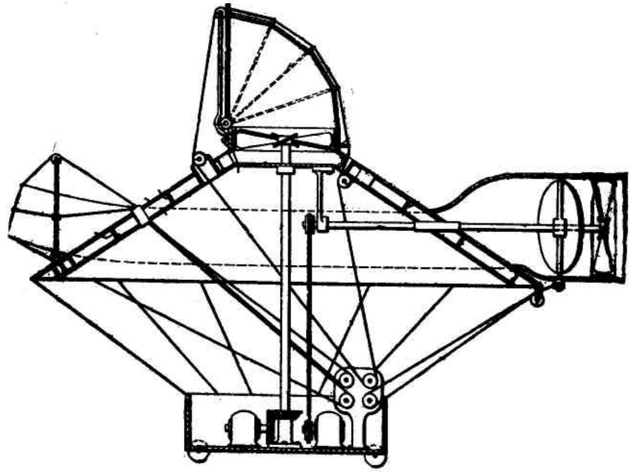


Figure 16. *This 1907 design by Joseph Clark appears to be the first using annular ducts*

JAMES R. PORTER, an English engineer, now enters the story with a series of Patents dating from October, 1908. In British Patent 21216/1908 and U.S.A. 1016359 (Fig. 17) Porter suggested a heavier than air flying machine having a tubular framework carrying a large diameter engine driven fan to force air out through a series of superimposed downwardly turned radial planes. Air acts on the underside of the planes and is deflected downwards to lift the machine. To counterbalance torque, two such arrangements are connected in tandem, and forward propulsion is obtained from a normal propeller. Although not strictly a ground effect machine, this appears to be the start of Porter's interest in such machines. The machine was built

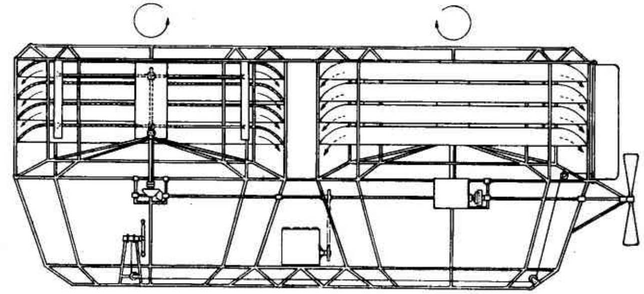


Figure 17. *This design by James R. Porter, an Englishman, marked the start of his interest in ground effect machines*

and exhibited at an aeronautical exhibition in London during 1909. The fans were 5 ft. in diameter and driven via belts and pulleys by a 5 h.p. motor.

In March, 1909, Porter obtained British Patent 5391/1909. This discloses a method of obtaining horizontal motion by adjusting segments in the air reaction surfaces.

In 1910 a new design of machine was suggested using a large fan drawing in atmospheric air and delivering the air through ducting so that it issues in a downwardly direction to lift and support the machine in the air. Again segments may be used for directional control and as a refinement Porter suggested the use of swivelling air discharge nozzles. In this Specification Porter says that in some cases it would be preferable to enclose the top anulus over the fan and draw air through apertures provided on the underside.

It would appear that he had second thoughts concerning the air intake entry to the fan as his British Patent of Addition 10703/1911 states that the arrangement for sealing off the top of the fan does not in practice give the best results. He suggests now that the bottom orifice is completely closed off and air is only allowed to enter through the top central aperture. He states that by closing off the lower opening a much improved lifting effect is obtained. The results of Porter's early experiments are given in his book published in England during 1911 and the illustration now shown (Fig. 18) is taken from this publication.

The next development was the subject of British Patent 15735/1912 where he suggests a number of fixed guide blades for better distribution of the air to the fan from the ducts. One point of interest in this specification is that it refers to aeronautical machines, marine vessels or road vessels, and on the illustration shown (Fig. 19) a buoyancy chamber is provided.

Directional control still appears to have been a serious problem and in January, 1913, Porter obtained a further Patent disclosing pivoted flaps spaced around the outlet duct and being manually operable to control air discharge and, therefore, direction of travel, operation of the flaps tends to tilt the machine producing forward motion.

In March, 1913, Porter suggested a machine which falls within the annular jet classification. The underside is completely closed and is elliptical in form. The engine and other mechanisms are enclosed to prevent break-up of smooth flowing air and to attempt silencing. Probably the most important of Porter's contributions is that described in British Patent 975/1914. This suggested a design very similar in principle to some of the machines being produced today. As shown in the illustration (Fig. 20), air is drawn over a large curved surface by a vertically mounted engine driven fan and then forced through an annular duct. The outlet of the duct is provided with a large number of

control segments which can be operated to direct the flow of air inwardly under a supporting surface or alternatively allow air to escape as required for directional control.

Further proposals of Porter's were made in 1915 which shows a machine capable of operating from water, the whole of the underside forming a built-in flotation chamber. If control segments are provided as described in the earlier patent, they are arranged to be drawn in and fit tightly to the sides of the flotation chamber when the machine is on the water.

A. U. ALCOCK 1912-1914 — AUSTRALIA

Probably the earliest "ground effect" man in Australia and one of the first practical men in this field was A. U. Alcock, formerly of Perth, Australia, but who retired to Devon, England, where he died recently. He was still doing a certain amount of work in his own workshop although in his 90s.

As an electrical and mechanical engineer working in Perth, Australia, early in the century, he built a working model of a "hovercraft" in 1912 and demonstrated it before the Press and Australian Government officials. The Australian *Sunday Times* of 1912 states that their reporter witnessed the demonstration and gives some details.

The model was simply a platform of wood 4 ft. x 4 ft. x 2 in. on which was mounted an electric motor driving a compressor and propeller. Air from the compressor was pumped beneath the platform, through a single orifice to provide a "cushion" on "levapad" principles. The propeller provided thrust to move the model and the inventor called this mode of travel "floating traction", probably a much better term than that of "hovercraft".

Provisional Patents were taken out in Australia in 1914, 14309/1914, but since the inventor received no backing these were not proceeded with. Other models of Alcock's were demonstrated at the Cricklewood Ice Rink in 1939.

THE WARNER STORY

The name of Douglas Kent Warner should be known to every "hovercraft" engineer. He is head of the Warner Research Laboratories at Tamiama Trial, Sarasota, Florida.

During 1928 he carried out a considerable amount of research and experimental work on air cushioned boats of the sidewall type and tested an outboard powered, ram supported craft on Lake Compounce, Connecticut in 1929 (Fig. 21). He delivered one to the U.S. Navy Building in Washington for test. Both of these craft had a tendency of letting a wave sweep the air out from under them and so stopping the craft abruptly. Warner redesigned his original craft and in 1930 drove it at the Middleton races on the Connecticut river.

U.S. Patent 1819216 shows that this craft had sidewalls or runners depending from airtight buoyancy chambers, spring-loaded flaps were fitted on the front and rear of the craft acting as non-return valves for air trapped beneath it at above ambient pressure.

The rear flap could be adjusted to sea conditions prevailing. Exhaust gases were used to help lift the boat from the water and a water propeller provided forward motion.

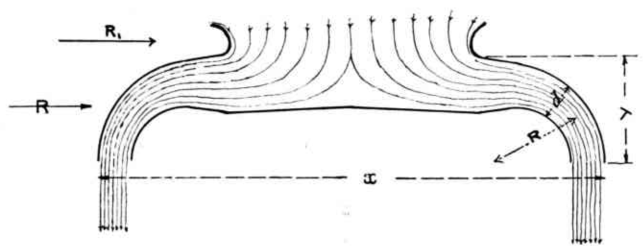


Figure 18. *One of the illustrations from a book written by Porter in 1911. It shows how by closing off the lower opening an improved lifting effect is obtained*

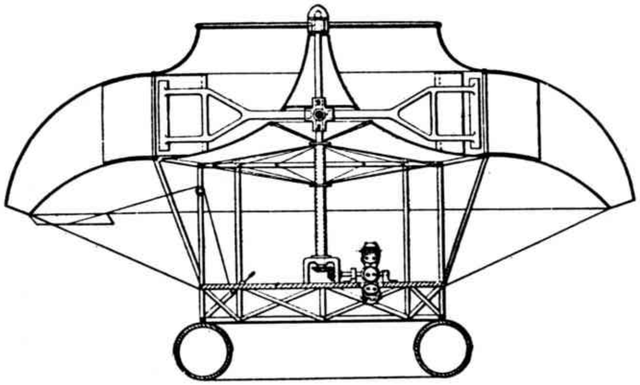


Figure 19. *In this patent of 1912 Porter suggested the use of fixed guide blades for better air distribution*

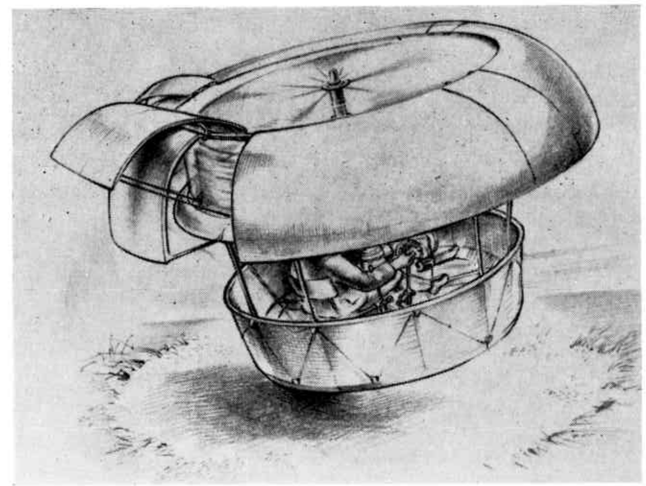


Figure 20. *Control segments for directional control were features of the proposal by Porter in 1915*

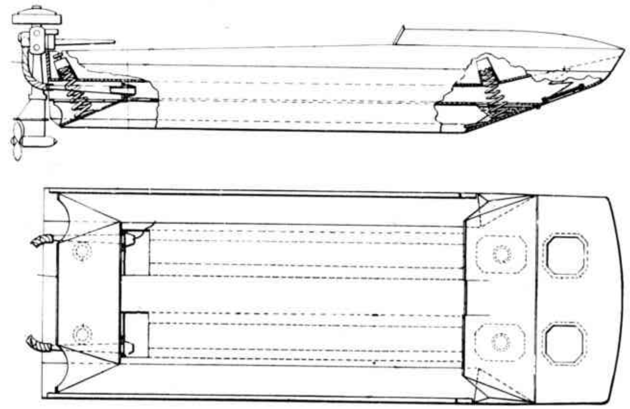


Figure 21. *Outboard ram supported craft tested by Douglas Kent Warner in 1929*

As the boat skimmed the waves the ram air pressure built up and the boat rose on an air cushion. The front and rear flaps were urged downwards by a spring mechanism to keep contact with the water and so maintain a pressure cushion. At the Middletown races this craft with a canvas tail flap weighted with steel balls was soon in trouble and so, too, was its inventor and pilot. The steel balls quickly wore through the canvas tail flap due to water friction and after rounding half the course it suddenly rose fifteen feet in the air and in returning to the water in a tail spin threw Warner out. This does not seem to have damped Warner's enthusiasm and by late 1930 he had designed and patented another sidewall cushion boat. But this time air propulsion was used in place of water screws. This second boat is shown in U.S. Patent 1855076. The air enters cylinders depressing the pistons and acting on the skids which raise the forward end of the boat as it gathers speed, ram air is forced into contact with the inclined bottom of the hull at the bow, which adds to the lift of the water skids and reduces the loading on the pneumatic

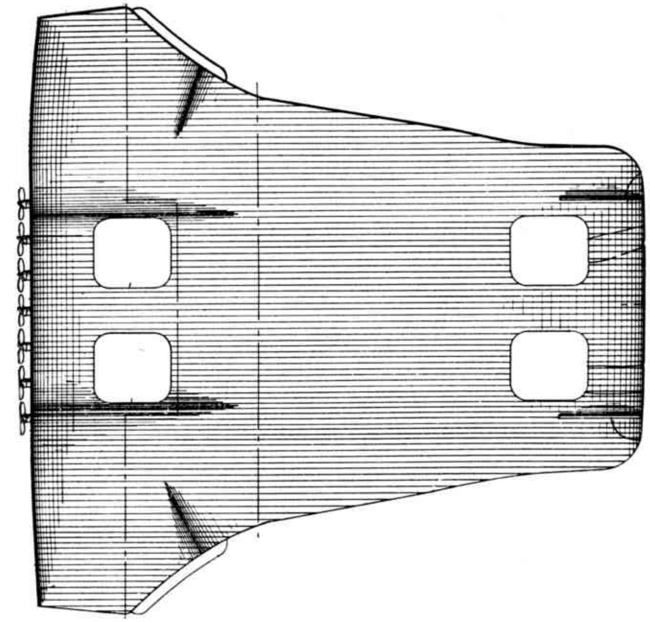


Figure 22. *Design for a ram wing skimming craft patented by Warner in 1939*

rams. The motion of the pneumatic rams gives more uniform lifting of the boat in varying sea conditions. The ram air escapes rearwardly.

It is not known whether a craft was built of this design but we do know that Warner's invention in this field of activity turned to ram wing skimming craft. His first ram wing machine was of most unusual design as the idea of a large air cushion craft using waterscrews and hydro-foils is being considered as tomorrow's solution to some of the more pressing problems of stability in Hovercraft.

His first machine patented in January, 1939 (Fig. 22), U.S. 2277620, shows a wide area flying wing with seven tractor propellers along the leading edge and a pair of downwardly projecting stubwings carrying water screws. The stubwings also acted as hydroplane surfaces. One unusual feature of this design is a power system whereby the heat energy extracted by the water coolant for the main engines was used to drive the water propellers in a closed circuit system.

By May, 1940, Warner had designed and patented the first of a long line of skimming craft or pressure planes, as he sometimes called them. U.S. 2365676 shows one of his machines.

U.S. 2364677 (Fig. 23) shows a ram wing of a Mach 2 aircraft. On starting the engines, air is compressed within the pressure chamber beneath the aircraft which raises it from the ground or water. As soon as the craft is clear and supported on its air cushion, it is free to make a skimming flight and on obtaining high speed it can climb above ground effect to altitude. During skimming flight back pressure in the pressure chamber will cause some of the air to be forced back up over the centre aerofoil section and down again rearwards to be speeded up by the jet stream issuing beneath it. Figs. 24 and 25 show scale models built by Warner. This design is covered by U.S. Patent 2390859 (Fig. 26). Warner has had issued to him a large number of patents relating to ground effect machines and the illustrations shown (Figs. 27 and 28) indicate the considerable research and development which he has carried out.

Another pioneer in the field of ground effect machinese was T. J. Kaario of Finland. He built and tested his first ground effect machine in 1935 (Fig. 29) — first as a glider and later powered with a 16 hp engine. The machine was 6 ft. by 8 ft. and attained a speed of 12 knots over ice on its first flight in late 1935. This machine was the subject of Finnish Patent 18630 granted to Kaario in 1935.

The craft shown in Fig. 30 made a considerable number of flights during 1935-36.

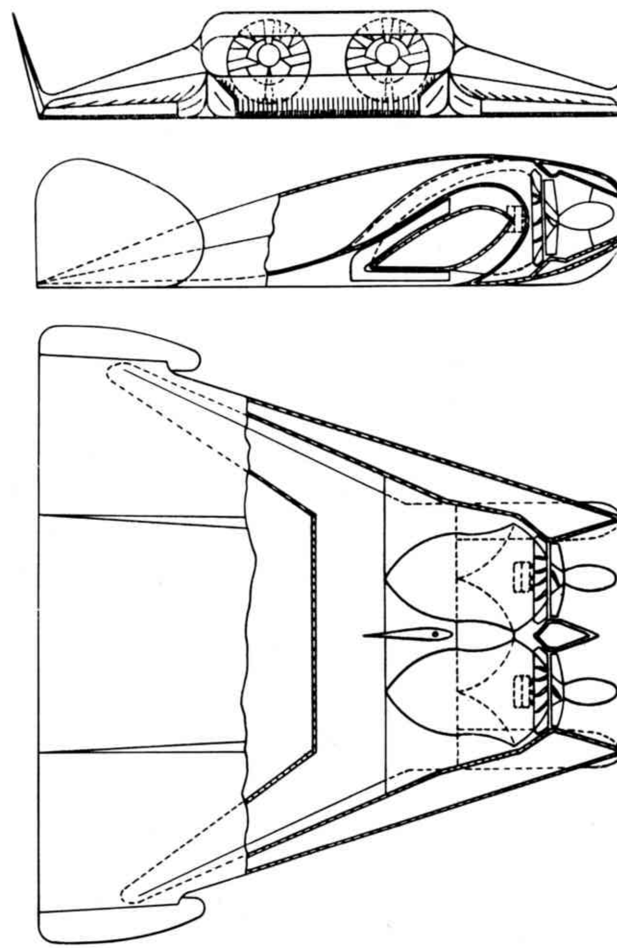
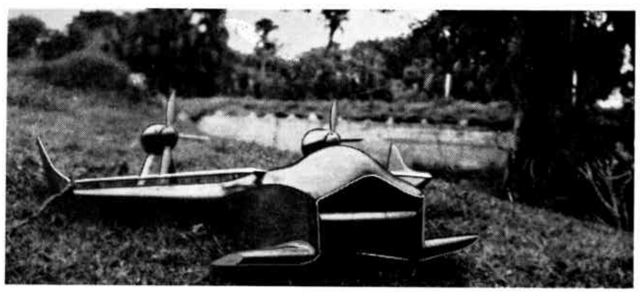


Figure 23. *Mach 2 aircraft with a ram wing proposed by Warner*

Finnish Patent 26122, of 1949, was a development of the earlier machines (Fig. 31). This machine was fitted with a 20 hp engine and made several controlled free flights towards the end of 1949. It is known to have hovered with four men on board, and tests were also made over the water. It is known that a 10 ft. craft powered with a Volkswagen engine has recently been built but results of tests are not known.

Figures 24 and 25. *Scale models used by Warner to demonstrate ram wing proposals*



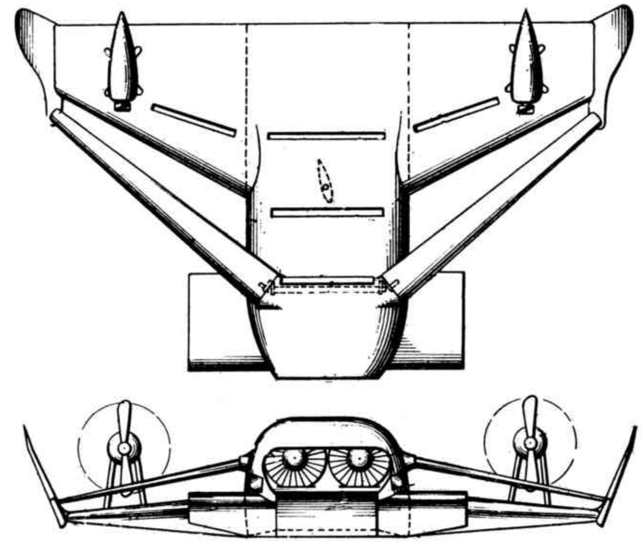
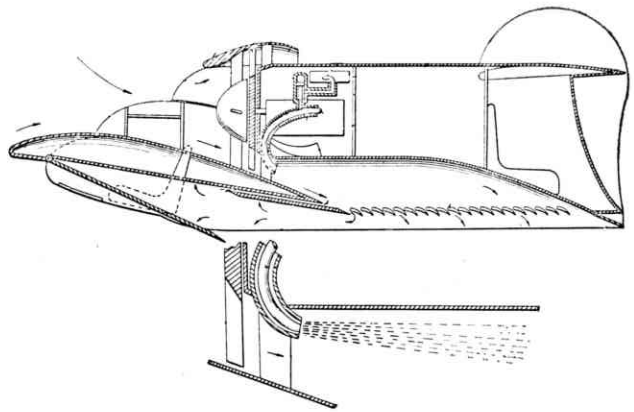


Figure 26. *Design by Warner covered by U.S. Patent* 2390859

The story of Christopher Cockerell, his experimental models and his fight to interest a manufacturer in his design proposals is too well known to need repetition here. The first British Patent issued to Cockerell No. 854211, dated December, 1955 (Fig. 32), illustrates his original proposals. An artist's impression of an early model is shown in Fig. 33. This patent which covers the peripheral jet concept with inturned jets has resulted in the rebirth of a new industry in G.B. and the formation of Hovercraft Development Ltd., who now own all patents and applications pending to Cockerell.



Figures 27 and 28. *Two more of Warner's designs indicating the extent of his research*

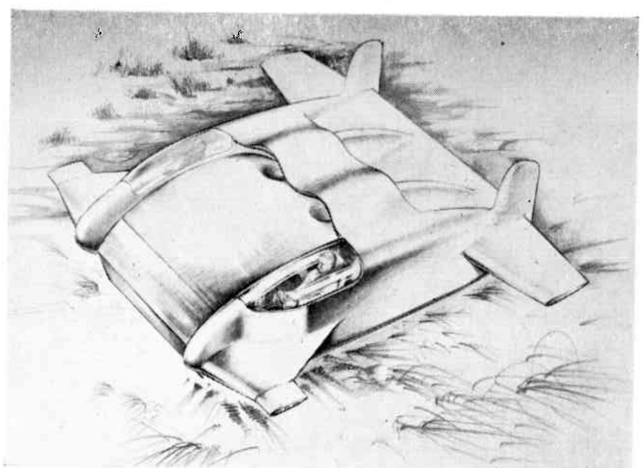


Figure 29. *Kaario's first ground effect machine, built in Finland in 1935. It attained a speed of 12 knots with a 16 hp engine*

The Saunders-Roe Division of Westland Aircraft, Vickers (South Marston) Ltd., and Denny Bros. of Dumbarton, have all produced machines in collaboration with H.D.L.

At least one man was thinking on the same lines as Cockerell at the same time and filed a Provisional Application for a Patent in Brazil during August, 1955. The specification of Renalto Alves De Lima shows a circular vehicle provided with counter rotating fans which draw air in from the upper edge of the craft, compress it within a plenum chamber and then discharge it through a peripheral jet to create a "column of air which reacted against confinement", and on which the vehicle rode 15-20 cms. above the ground. (Fig. 34.) Propulsion, he said, could be by an outboard motorised propeller or a jet emanating from the machine itself.

Quoting from de Lima's Specification it is stated that:

"The craft flies skimming the surface, always following the undulations of the road, rising and descending, always airborne and away from the ground, with no assistance from the pilot; this work is performed by the craft itself which skims over the obstacle and down again just as if it were travelling on wheels. Thus on climbing a slope the vehicle tilts backwards, and going down it tilts forwards.

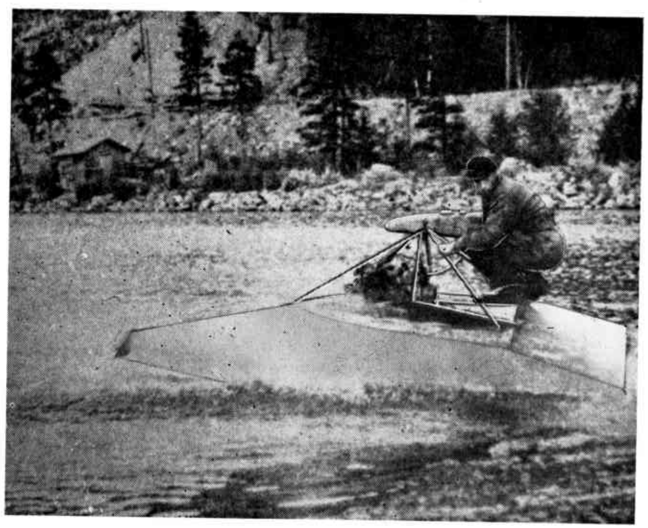
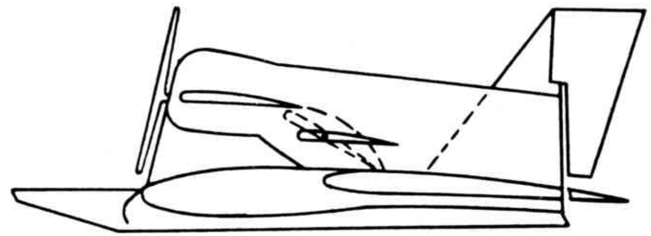


Figure 30. *Craft tested extensively by Kaario during 1935-6*



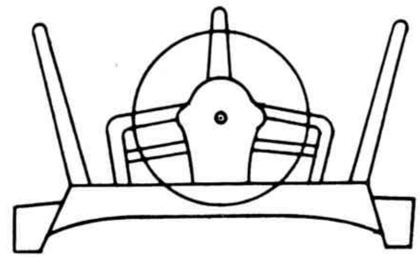


Figure 31. *A development of Kaario's earlier machines, this craft made its first flight towards the end of 1949*

"This column of air does, however, maintain the craft airborne with less power than an ordinary aircraft would require. Steering is effected by rudder and controllable blades or vanes which deflect the air discharge".

De Lima further stated that the craft may be built in various shapes; round, triangular, etc., and may be supported by one or more columns of air or even two parallel columns. (Fig. 35) forms part of his patent application.

In another embodiment of his invention he stated that an aeroplane could use an air cushion in place of conventional landing gear, thus dispensing with expensive runways, etc. (Fig. 36.)

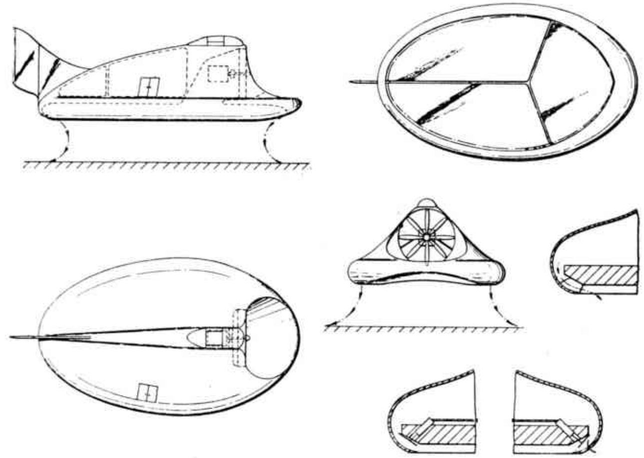
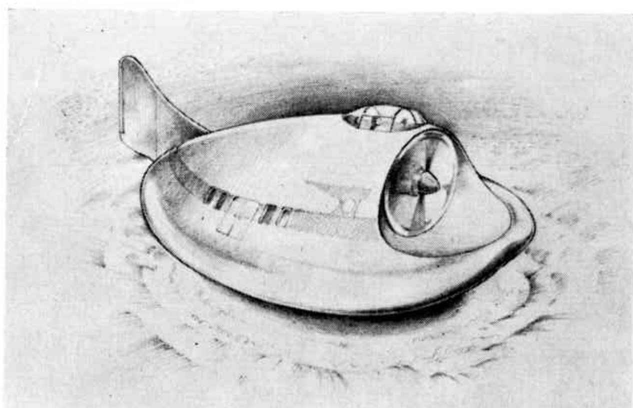


Figure 32. *Christopher Cockerell's original Hovercraft proposal*

Figure 33. *An impression of an early model of Christopher Cockerell's original design*



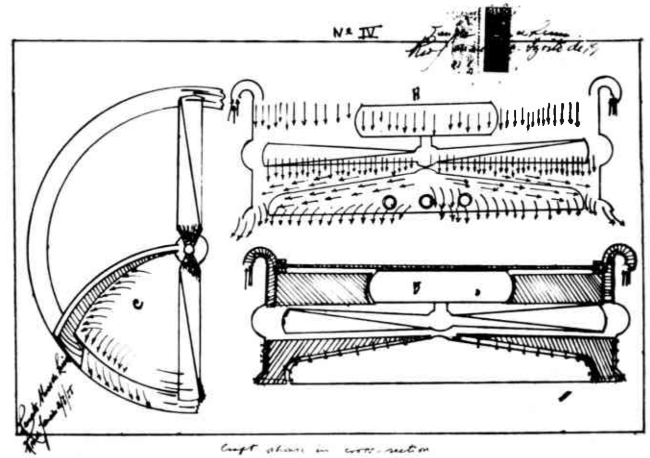
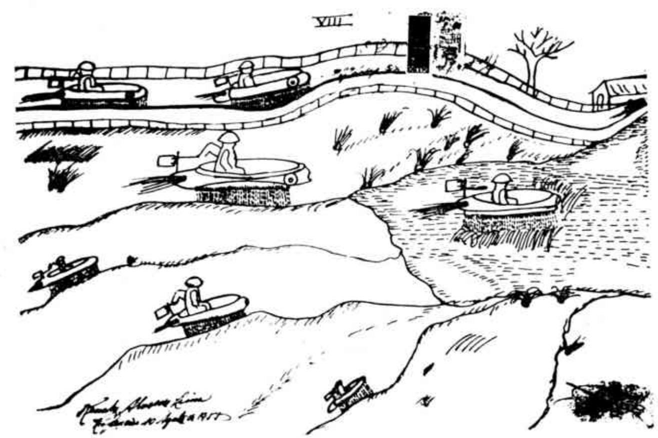


Figure 34. *A provisional application for a patent for this machine was filed by Renalto Alves De Lima in Brazil in August 1955*

Figure 35. *De Lima stated his craft could be built in various shapes and be supported by one or more columns of air or even by two parallel columns*



The drawings in de Lima's specification are crude and his technical description is not that of an engineer, but there is no doubt that he had the basic idea of a ground effect vehicle using a peripheral jet system.

The difference between de Lima's idea and Cockerell seems to be that his (de Lima's) jet discharges vertically downwards.

Unfortunately, de Lima could not raise a spark of enthusiasm in anybody in his country and was not prepared to go to the expense of completing his Patent. Consequently, his disclosure has no effect upon subsequently issued patents.

The only Swiss project is that of Carl Weiland who was an engineer with the Federal Aircraft Organization at Emmen, Switzerland, and is now in the United States.

Weiland was an exponent of the labyrinth seal system and it is known that he has constructed two machines of

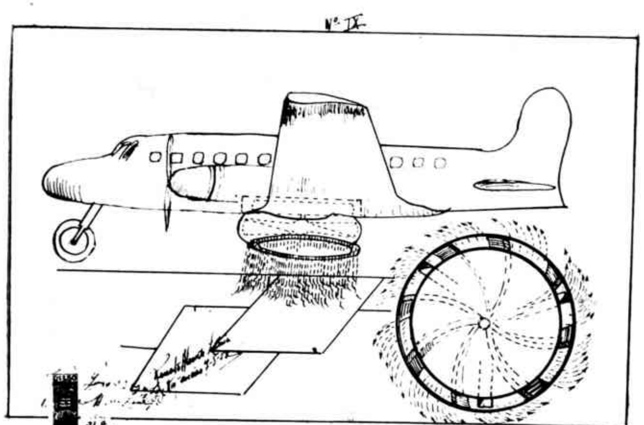


Figure 36. *One of De Lima's proposals was that his air cushion invention should be used on an aircraft in place of a conventional landing gear*

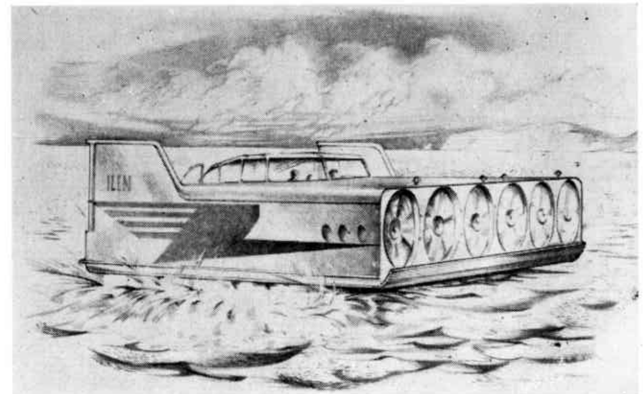


Figure 37. *Carl Weiland constructed two of these machines to demonstrate the labyrinth seal system*

the configuration shown in (Fig. 37). This machine was approximately 35 ft. x 30 ft. and had six forward facing air intakes each housing a fan. Two engines developing 700 h.p. were used and the machine is reported to have reached a speed of 60 m.p.h. over water on Lake Zurich. The first of these craft sank through some unexplained accident during a heavy storm and the second one has now been acquired by the United States Navy for research work. It is not known whether this second machine is the rebuilt salvaged machine or one of entirely new construction.

(Fig. 38) shows the labyrinth seal principle used by Carl Weiland and patented in October, 1957. Air drawn in from leading edge intakes is compressed in annular compartments separated by steps or labyrinths and as it escapes from the inner compartment it is drawn up by a fan in the next compartment and turned back upon itself.

This method of recirculating the air is an attempt to reduce engine power requirements.

Further interesting projects have been developed by A. V. Roe in Canada, known as the Avro-Car and many

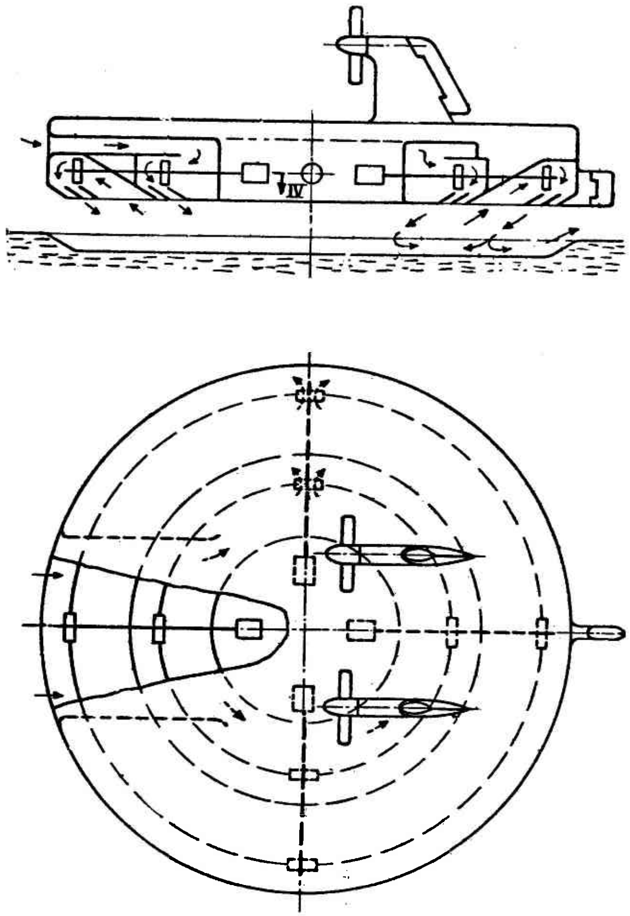


Figure 38. *Carl Weiland's labyrinth seal principle patented in October 1957*

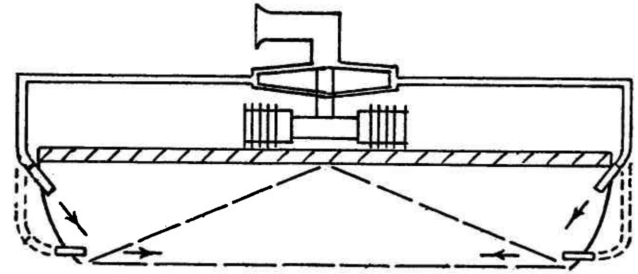


Figure 39. *C. H. Latimer-Needham's design for a flexible skirt*

patents have been issued or are in the process of issuing covering the engineering of this machine.

The Canadian machine is a combination of peripheral jet and lentiform wing. Work commenced in 1955 but has recently been abandoned.

An invention which is proving to be of considerable importance was made by an Englishman, C. H. Latimer-Needham, during 1958. This invention is covered by British Patent 860781 (Fig. 39) and relates to the provision of flexible skirts which can be adapted to any form of ground effect machine to maintain the air cushion at a considerable depth, thereby giving a greater clearance height in operation. This patent has been acquired by Westland Aircraft Ltd.

The first machine produced in France has been named the Terraplane by its inventor and manufacturer, M. Bertin (Fig. 40). A rectangular platform 24 ft. long, 11 ft. wide, houses eight small units which provide the air cushion. Tiltable, flexible skirts 22 in. in depth and 5 ft. in diameter are fitted to each of the eight units. This craft has an unladen weight of 3,300 lb. and can carry a load of 3,300 lb. A turbo jet engine developing 880 lb. thrust feeds air through eight large bore tubes. The action of the skirts is shown in (Fig. 41).

Great interest is being shown by the French Army.

The platform of the machine is at present being filled with an expanded plastic material to provide buoyancy and enable water trials to take place.

CERN

A number of industrial uses have been put forward which utilise an air cushion. One such proposal has been made by the European Organization for Nuclear Research and in this case a load of 30 tons was moved on four discs of 500 mm. diameter, the friction coefficient on a smooth concrete floor was about 1% whereas the co-efficient for a smooth steel plate on the same floor for the same specific pressure amounts to about 30% (Fig. 42).

The air cushion system can be built as an integral part of a machine or alternatively they can be adapted to be fitted under the apparatus which needs to be moved.

This work was originally started in early 1957 and developments are still proceeding.

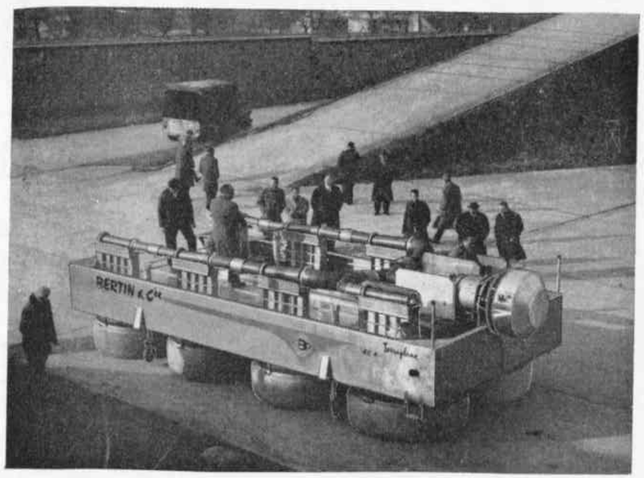


Figure 40. *The Bertin Terraplane*

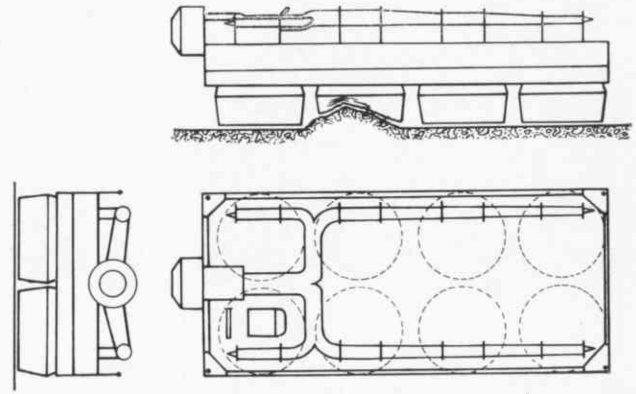


Figure 41. *Skirt action on the Bertin Terraplane*

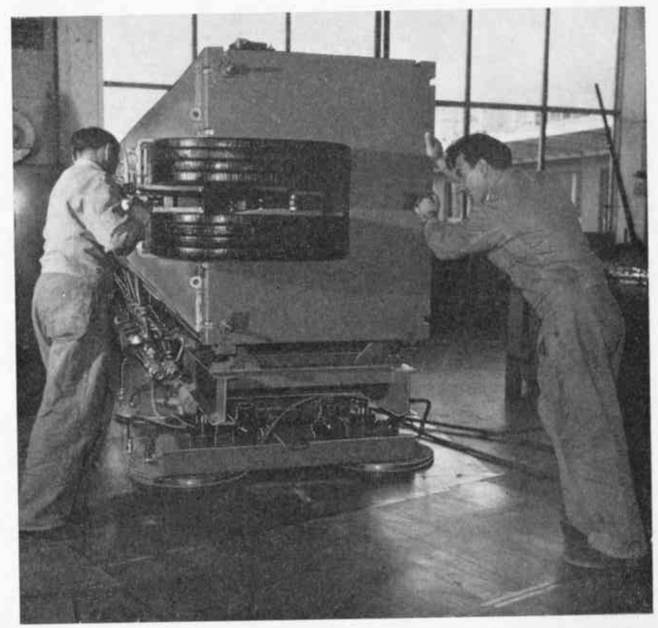


Figure 42. *Industrial use of the air cushion is illustrated by these applicators designed by the European organisation of Nuclear Research for moving heavy components by hand*