Hovercraft & Hydrofoils

work like this

AN ILLUSTRATED INTRODUCTION

Egon Larsen

Hovercraft & Hydrofoils work like this EGON LARSEN

DENT

'SCIENCE WORKS LIKE THIS' SERIES

EGON LARSEN

Hovercraft & Hydrofoils Work Like This

With 53 line drawings by Charles Green

Is it a ship or an aircraft? Strange new means of transport have sprung up in our time, but none stranger than hovercraft and hydrofoils. We are not even quite sure how to classify them—the air-cushion vehicle (as the hovercraft is called in technical language) flies above the water and the ground like a bird, but can't rise more than a few feet; the winged or legged boat—the hydrofoil—almost leaves the water, but cannot move without it. These surface-skimming craft (another technical term) have opened a new world of inventive imagination to our transport designers. We shall probably travel in air-cushion vehicles at high speed over land as we already do over the water; aero-trains, hovercars, giant ocean-going hydrofoil ships are in the offing, and air-cushion techniques have been introduced in medicine and industry. Oddly enough, even a combination of hovercraft and hydrofoil boat is being developed.

The story of the hydrofoil (which started before the first aeroplane flew) and the recent one of the hovercraft, which began in Christopher Cockerell's shed with an empty coffee tin, are told in this fascinating book. The exciting possibilities of the future are described in text and pictures; no less important are the lucid explanations of the scientific and technical principles of these new vehicles.

This is Egon Larsen's fourth book in the 'Science Works Like This' series after his successful *Radar*, *Transistors*, and *Lasers*, all of which have proved popular with young readers.

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ILLUSTRATED BY
CHARLES GREEN

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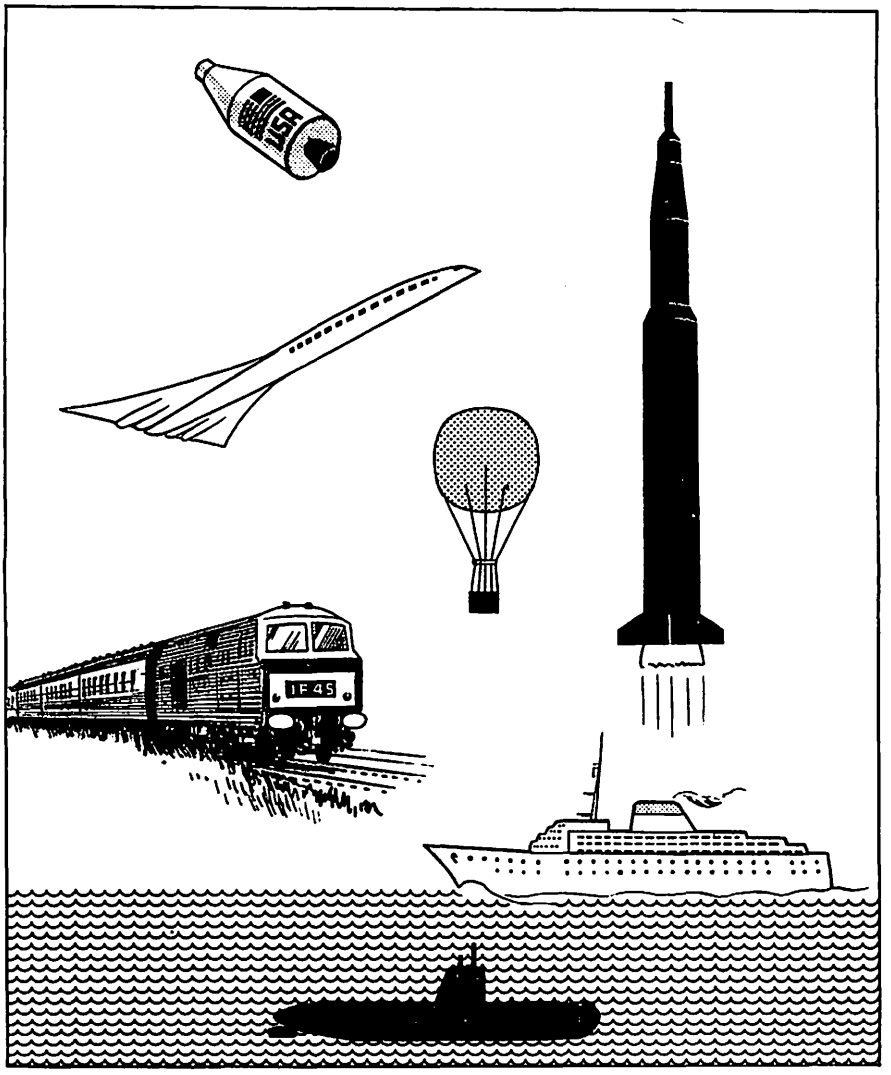
1 Floating, Flying and Skimming

For a few thousand years, Man seems to have been quite happy with the few means of transport he had apart from his own feet—wheeled carts, rollers and sledges on land, and rowing and sailing boats on water. Of course, he dreamed of being able to fly like the birds, of magic carpets and seven-league boots that would take him from one place to another at great speed and with no effort of his own, or of descending into the depths of the sea in underwater ships. Some great scientists, like the painter Leonardo da Vinci, tried to discover the natural laws that must be tackled in order to free Man from the restrictions of slow land and sea travel: friction and buoyancy, gravity and reaction.

Only during the last two centuries, scientists and inventors succeeded in breaking down those restrictions one by one. The steam-engine provided the first 'prime mover' as a source of energy not only for the factories but also for faster transport on land and at sea. The hot-air and hydrogen balloons lifted human beings for the first time from the earth. Around the turn from the nineteenth to our century, a whole spate of inventions opened up a new world of transport: the petrol- and the diesel-engine brought the motor-car, the airship, the submarine and eventually the aeroplane; the steam-turbine made larger and faster ships possible; and later came the jet-engine, the gas-turbine, and the rocket. We have reached the moon, and we are reaching out for the planets, thanks to the development of science and technology.

Let us take a closer look at the way in which modern vehicles move on land, at sea, in the air, and in airless space. Land vehicles, such as the railway and the motor-car, make use of the oldest of Man's technical achievements, the wheel. When it was invented—we don't know exactly when and where—the genius (or geniuses) who developed it from the rolling log that had served in moving heavy loads from place to place, was probably quite unaware of the physical basis of his invention: that it reduced friction to a minimum, and that it was using the force of gravity—two factors which play their part when anything is moved from one point to another. Nor did the first boatbuilders have any idea how their wooden hulls were supported by the water. It was only in the late eighteenth century that inventors started out from some scientific theory, understood the laws of nature, and used them successfully to create new machines or

means of transport. James Watt's steam-engine was a product of physical theory as much as of practical experimenting; the Montgolfier brothers knew that warm air is thinner, and therefore lighter, than the surrounding atmosphere and would carry a balloon up; and their rival, Professor Charles, went one better by using the gas hydrogen, which he knew to be lighter than air, to make his balloons rise. The whole history of the utilization of electricity, which extended throughout the nineteenth



Vehicles and the media in which they move—train, balloon and aircraft in air, ship in water and air, submarine in water, rocket in air and airless space, interplanetary vehicle in airless space

century, is one of scientific reasoning and experimental development. Perhaps the most striking example of a scientist-inventor is that of Rudolf Diesel, who made his first notes on an 'ideal heat-engine' during lectures at the technical high school, and later strove for many years to put those ideas into practice until he had created his engine.

But it had taken the technologists a long time to realize that some vehicles are subject, in their movements, to two sets of natural laws because they travel in two elements. Only the submarine, the aircraft and the space-ship travel in a single element; trains and cars travel on the boundary between land and air, ships on the boundary between water and air. A ship has to tackle two elements, water and air, each with a set of complicated laws and ways of behaviour, and from this point of view the aeroplane might be regarded as a simpler means of transport; pushed through the air by its jets or propellers, it is supported by the pressure below its wings created by the airflow—but it cannot stand still, or its support will vanish. A balloon or airship, however, will stay up even without wind or engine action because it relies on its buoyancy, like a ship in water. A helicopter, too, can remain in the air without horizontal movement; but it needs the lifting action of its rotor, which is, in fact, a set of revolving wings. Farther out, in airless space, there is no aerodynamic problem because there is no air; nor any force that tries to pull the space-ship back to earth once it has left the gravitational field of our planet. This is the reason for the condition of weightlessness which the astronauts experience. And as there is no medium through which the vehicle travels there is also no friction that could brake its journey: it will travel on and on at the speed at which it has left the gravitational field of the earth until it gets into that of some other planet, or the sun may attract it and force it into an eternal solar orbit. So the space-ship must be controlled by rocket action to steer it wherever it is supposed to go. That action does not depend on any element to push against; Isaac Newton stated the principle of the rocket engine in his famous third law of motion: that to every action there is an equal and opposite reaction. It is the force of the hot gaseous matter ejected from the rocket nozzle that propels the space-ship.

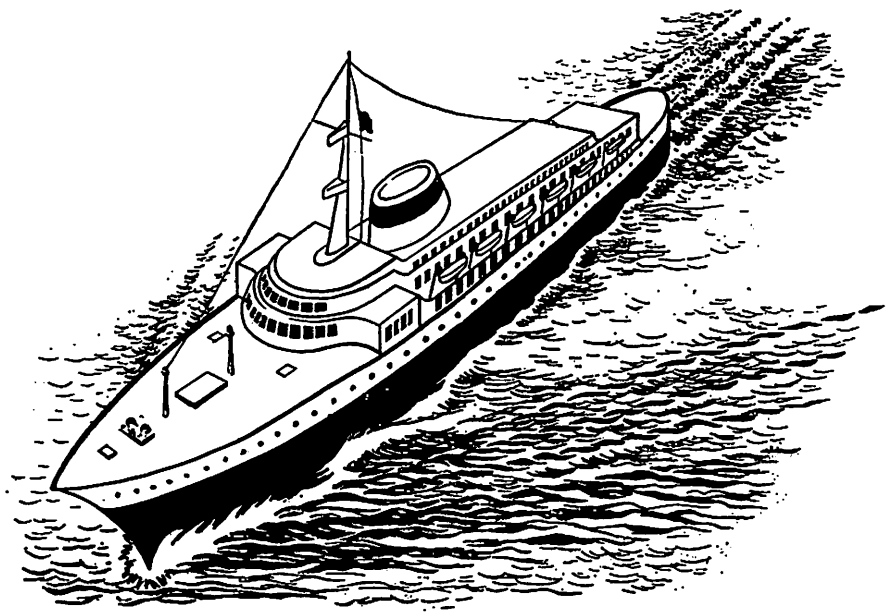
'Boundary' vehicles—those moving in the regions where the atmosphere meets either land or water—seem to work by straightforward physical principles, but that simplicity is deceptive. On the ground, the wheel helps to overcome friction, but it also provides the necessary support for the vehicle by the reaction of the hard ground to the weight of the vehicle—a support that is there whether the vehicle moves or remains stationary. George Stephenson had a very shrewd idea of these principles when he carried out his studies and calculations on friction and gravity before trying to interest the public in his steam-railway schemes; as a result of his

theoretical work, he came to the conclusion that steam-traction and rails 'belonged together like man and wife'.

In Stephenson's days, air resistance through the rapid motion of a ground vehicle was no problem; it emerged only in our century as trains and motor-cars were gathering speed, and the 'boundary' zone began to demand the scientists' and technologists' attention. That was the time when a new word for a new concept entered into everyday language: 'streamline', meaning a vehicle shape which causes the least air resistance when moving at speed.

The boundary problem makes itself most strongly felt in the propulsion and design of ships. The whole of a surface ship's support comes from the water; it was Archimedes, in his classical study on 'Floating Bodies', who stated the natural law of buoyancy for the first time: that a body immersed in a fluid is subject to an upward force equal to the weight of the displaced fluid.

So far as the element water is concerned, the ship is therefore helped by receiving its support from it, but at the same time hindered by very considerable resistance. The power required to move a ship *on* the water, which means also partially *through* it, depends first of all on the strength of



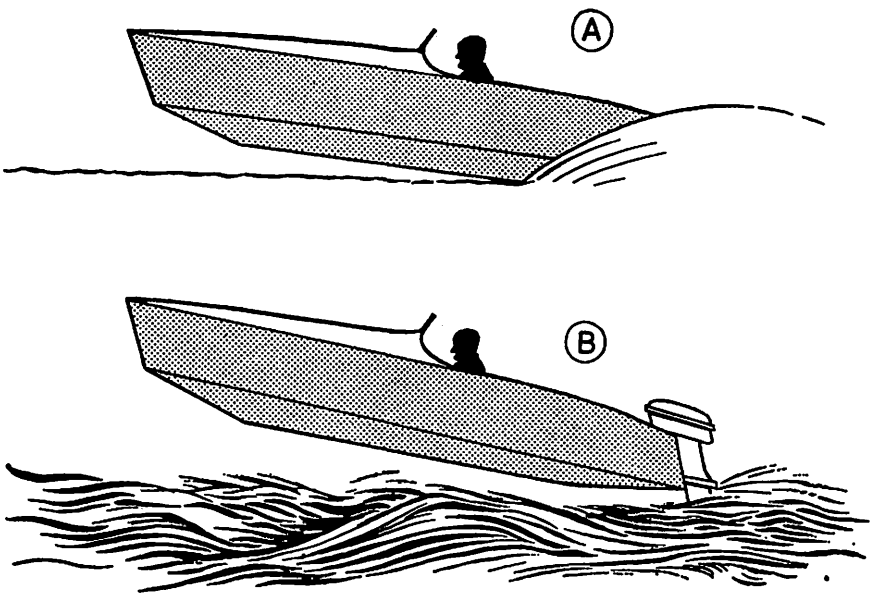
The movement of a ship is hindered by water and air resistance and by the drag it creates itself: by bow waves and wash

that resistance, whose main cause are the waves made by the boat itself; they are created at the front—the bow—as well as at the rear—the stern—of the vehicle, and tend to slow it down. Then there is the so-called viscosity, or 'stickiness', of the water, which causes friction between the hull and the water.

And being a 'boundary' vehicle, the ship is also subject to air resistance, which grows with the speed: in fact, it increases by the square—if the speed doubles, for instance, air resistance grows four times greater. This, of course, does not take into account the help or hindrance the ship gets from the wind.

Water and air resistance together make up the 'drag' to which the moving ship is subjected, and so the shipbuilder's task is to reduce the drag by choosing the most efficient relationship of design, size and propulsion; the length and weight of the vehicle, its most economical speed and a host of other factors must be considered and computed.

It has been said that a ship, even the most up-to-date one, is a slow and not very efficient means of transport due to the tricky combination of resistance factors of the water and air through which it has to move



Speed boat on A. *smooth water:* B. *rough water.*

First attempt at reducing water resistance in ships; the speedboat. It is fast, but a rough sea surface gives it a terrible pounding

against drag. Modern technical thought has, therefore, turned to possible ways of reducing that resistance, and it is the water which seems to appear as the villain of the piece; the ship acts like a wedge cutting through a great mass of water—equal to its own weight—and must waste much of its energy coping with waves and wash of its own making, plus the waves and currents which the sea sends in its way. Some technologists and inventors thus tried to lift the ship wholly or partly out of the water, making it skim over it while retaining at least some of the support the water offers. The speedboat is one solution, but perhaps you have to be a sportsman to endure the pounding of a rough sea for the sake of rapid motion; besides, it is frightfully uneconomic and cannot be built in larger sizes. But there are two other types of 'skimmers' which have already proved their great value in modern transport, and it is with these that our book deals.

2 The Coffee-Tin Invention

THERE is something about the 'lone' inventor that appeals to all of us, and although we have been told often enough that he died out with Edison, we still refuse to believe that this type of technical revolutionary has disappeared for ever. Has the big-industry research team with its vast laboratories and unlimited facilities taken his place for good? Is there really no room for him in our world of corporations and committees, of 'working parties' and government departments?

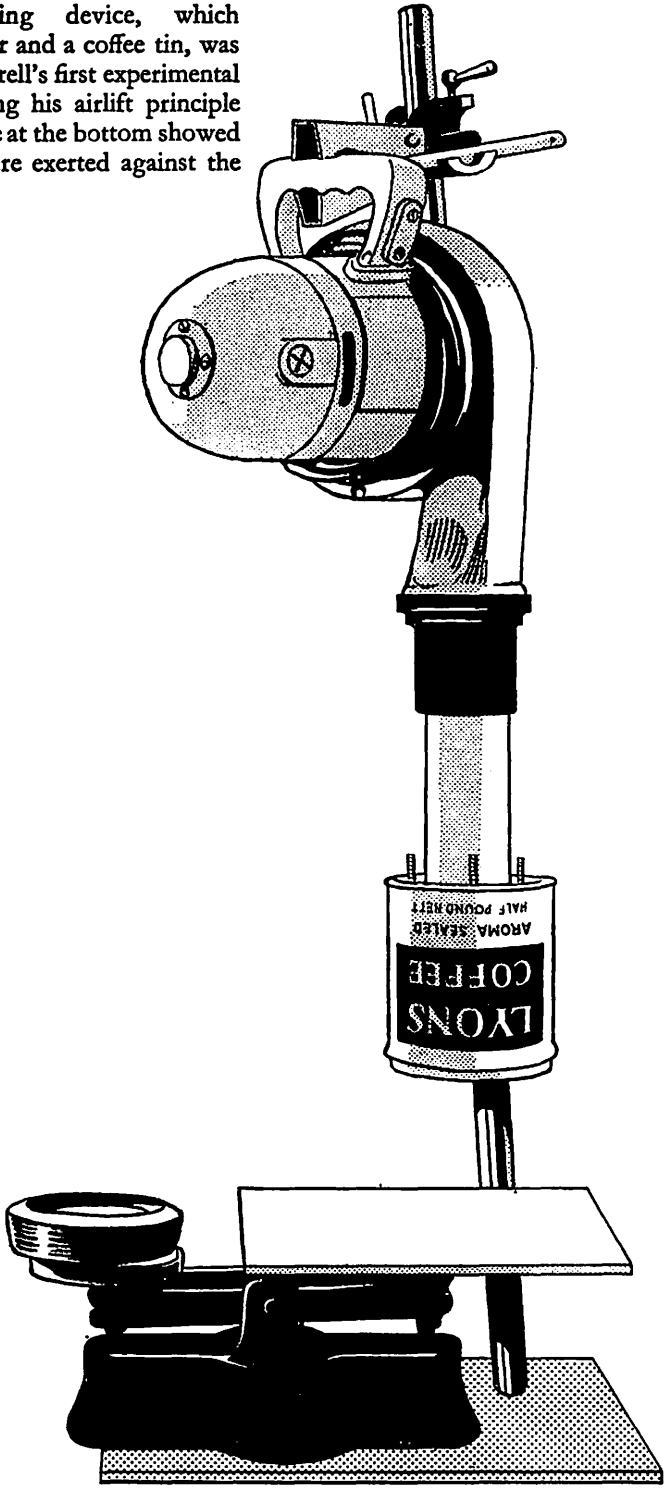
Every now and then, fortunately, our belief that the individual, independent inventor still exists is being confirmed in no uncertain manner, and one of the most spectacular recent cases is that of Christopher Cockerell—now Sir Christopher.

This ordinary-looking, inconspicuous and rather shy Englishman had spent most of his working life as a development engineer in the electronics industry, trained to investigate technical problems, to question everything, and to wonder whether there may be some better way of doing things. When he was thinking about his retirement he bought a little boat-yard on the Norfolk Broads; ships had always been his hobby, and now that he was about to leave the electronics industry he wanted to devote all his time to them, building them and reading about them. That was in the early 1950's.

'Very soon in reading about boats,' he wrote, 'one comes upon the problem of wave resistance. This, one notes, is a law of nature—that is, something one cannot remove. All one can do (if other things permit) is to design so that it shall be a minimum. One then comes to skin friction. And of course, if you design for minimum wave resistance you are likely to get maximum skin friction, and vice versa.'

What Cockerell meant by this was that in order to make boats overcome wave resistance, you had to design them long and slim; but if they are long they have a large 'skin' or surface area, which means that the water drags on the hull and absorbs a lot of power. The boat shape that offers the least water-friction is the one that has the smallest ratio of surface area to volume—a sphere. But a circular boat would offer very great resistance to the waves, and could therefore move only rather slowly. So the problem was how to fulfil the requirements of low wave resistance and low water drag at one and the same time.

This weird-looking device, which includes a hairdrier and a coffee tin, was Christopher Cockerell's first experimental assembly for testing his airlift principle (1954). The balance at the bottom showed him the air pressure exerted against the ground



Cockerell reviewed, in his mind, the whole domain of transport. He saw that there were only two basic kinds of vehicle-movement over a surface: either by sliding along or by rolling along; most land vehicles roll on wheels, all water vehicles (at least those that existed at the time) slide. But there were exceptions among the land vehicles—the ski, the sleigh and the skate, and these interested him just because they were exceptions. These winter vehicles move on ice or snow so well because friction melts a tiny quantity of the ice or snow, thus providing lubrication by water. This gave Cockerell an idea: if the bottom of a boat could be isolated from the water surface by some other lubricant, friction would be reduced. There was only one possible lubricant that could be put between the solid hull of a ship and the fluid mass of water, and that was . . . air. So far, so good. But how do you get air under a boat, and make it stay there?

'After I had learnt from, and found out the shortcomings of "air lubrication" experimentally,' he wrote, 'the first idea I had was fixed side-walls with hinged doors at the ends, with air pumped into the centre. The next idea, at about the end of 1954, was fixed side-walls with water curtains sealing the ends. I stuck here for a bit, because I didn't know enough to be able to work out the probable duct and other losses and the sort of power that would be required.

'Then one Sunday evening I thought I would have a look at using air curtains. A simple calculation looked all right on a power basis, and so that Sunday I made up an annular jet using two coffee tins, and found that the air did follow the "predicted" path and that there was a "predicted" gain in lift—very exciting.'

That contraption made of two coffee tins, with Mrs Cockerell's hair-drier to supply the air—a harebrained-looking device if ever there was one in the history of invention—is now in the South Kensington Science Museum among the great 'firsts' of technology.

At this point in our story we might stop for a moment and look back. Has there never been, before Cockerell, any scientist or inventor who thought of using compressed air to provide lift or lubrication?

As a matter of fact, there were quite a few. Early in the eighteenth century the Swedish scientist and philosopher, mystic and royal defence engineer, Emanuel Swedenborg, designed a hover-parachute, but could not find a power unit for supplying the necessary quantity of compressed air—steam-engines were still in their infancy, and human muscle power did not suffice. After Watt, however, several inventors tried out steam-powered air-lubrication systems, and a French inventor patented his idea of using the steam itself as an air 'cushion' in 1859. Twenty years later, the famous British naval architect Sir John Isaac Thornycroft, then only in his early twenties, took out a patent which read: 'In order to reduce the

friction of a vessel when travelling on water I interpose a layer or body of air between the bottom of the vessel and the surface of the water, which air I confine within a cavity at the bottom of the vessel, such air being maintained at such pressure as to keep the cavity filled, or nearly so, such air as may escape being replaced.' Needless to say that the technological means available in the 1870's were unable to provide Thornycroft with a motor sufficiently powerful for the purpose; a torpedo-boat hull with an aircushion, which he demonstrated to the Admiralty, did not come up to expectations, and the idea was dropped for the time being.

In our century, Australian, French, Austrian and American inventors designed and built boats and land craft supposed to float on aircushions —the last one, in the 1950's, an American colonel, Melville Beardsley, who later tried to get his claim of priority acknowledged against that of Cockerell; but Cockerell won. As it has happened so often, the spark of inspiration was not enough; it needed a great deal of effort—or perspiration, as Edison put it—to fan that spark into a nice big fire. And Christopher Cockerell was the man who, in his quiet, stubborn way, plodded on where others would have given up.

There was a fellow boatbuilder at Oulton Broad, Mr A. D. Truman, who agreed to help him construct a beautiful little working model of the kind of vehicle the inventor had in mind: one that could move over land as well as over water on a cushion of compressed air. It was tested—and filmed by Cockerell with his amateur ciné camera—on a lawn and on a lake. This model, too, is now in the Science Museum.

The tests were so successful that larger working models could be built with confidence. Cockerell used first a punt fitted with a fan, and then a 20-knot launch. He found that the aircushion would have to be quite thick, at least as deep as any obstacles on the surface over which the craft was to travel, and that included waves. It was no problem to build up the cushion of compressed air, generated by powerful fan engines, underneath the craft—but the question of how to contain it caused Cockerell many a headache. First he considered making a 'box' of thin walls with hinged flaps at bow and stern; but the rigid flaps could not be expected to follow the shapes of the wave-tops, and the air would escape. Then he experimented with moving curtains of water instead of the end flaps; but the air pressure would bend them out of place, and a separate pumping system would have to be installed to counteract this, adding too much weight to the craft.

In the end he decided that the cushion could be 'sealed' into place by a curtain of continuous air jets directed downward and inward all around the periphery of the craft; he also concluded that the pressure of the aircushion would produce a substantial upward force. Cockerell was now convinced that he had created a really new means of transport for people

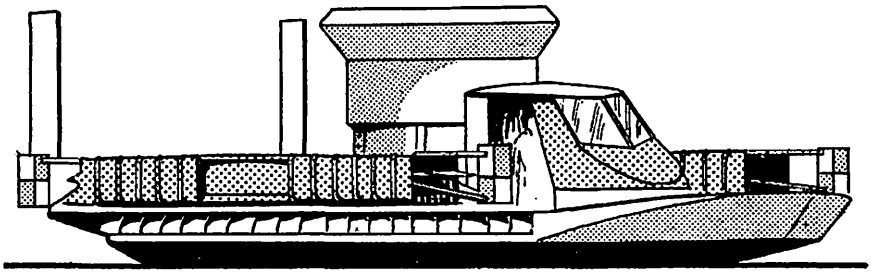
and goods over land or water at high speed, with friction and surface drag reduced to practically nil.

However, there is a vast difference between convincing oneself and convincing others, especially if they are supposed to back the further development of the invention with money. In December 1955, Cockerell applied for his first British patent concerning 'lift by means of peripheral annular jets of air', and began the tedious round of industry, government departments and potential backers. The shipbuilding companies said, 'It's not a ship, try the aircraft industry,' and the aircraft companies said, 'It's not an aeroplane, try the shipbuilders.' The engine manufacturers said, 'Very interesting, but not our line. However, if someone takes up your invention, remember to use our engines!' Cockerell, who was acquainted with these people in various branches of industry and with their characteristic ways from his time in the electronics industry, was not in the least discouraged. 'Not surprising,' he remarked. 'It's always difficult to get new ideas taken up; and the extreme newness of this idea makes it doubly difficult.'

But the greatest difficulty was yet to come; for all that Cockerell achieved during the whole first year of trying to get backers was that the government put his device on the secret list! This happened in November 1956, when he seemed to be getting his first big break at last: he succeeded in putting his report on the invention on Lord Mountbatten's desk, and in due course Mountbatten—then First Sea Lord—got the Admiralty and the Ministry of Supply to watch a demonstration of the small-scale model. But now that the hovercraft, as Cockerell called it, was put on the secret list because it might have military significance, he was not permitted to build a full-size prototype and demonstrate it.

However, things were moving at last. The model demonstration had been watched by, among other Ministry of Supply officials, the Deputy Director of Aircraft Research, Mr Ronald Shaw, who was a leading aerodynamics specialist with a splendid record of giving encouragement and developing unusual technical ideas; he had helped, during the Second World War, to carry out the 'bouncing bomb' idea of the inventor Dr Barnes Wallis, used by the R.A.F. 'dambusters', and later assisted Wallis with his designs for swing-wing aircraft. Ronald Shaw was absolutely convinced that Cockerell had a winner on his hands, and in 1958 managed to get him a small sum—a mere £7,500—in the form of a contract placed with the famous aircraft firm of Saunders Roe, for the building of a full-size hovercraft.

Now the pace of events quickened considerably. The hovercraft was taken off the secret list, and within ten months the prototype—SRN 1, 'SR' standing for Saunders Roe—was designed and built. In June 1959 it was completed, and immediately underwent trials in the Solent.

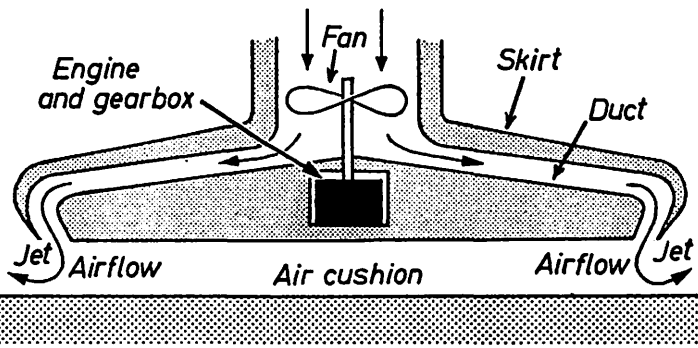


The first full-scale hovercraft: the SRN 1 (1959)

The small number of spectators who had been invited to watch the first journey of a manned hovercraft were not quite sure what to make of that strange vehicle. Just over 31 ft long and 25 ft wide, with an enormously thick 'funnel' in the middle, it seemed unlike any other known vehicle. At first it floated, slightly rocking, on the waves of the Solent; then there came a great roar of engines, a spray of water shot up all around the craft, and it rose a foot or so above the sea. Now it began to move, faster and faster, until it reached a speed of 25 knots. But the greatest sensation was yet to come. Without slowing down, the vehicle returned to the beach, skimmed over the sand, climbed up the gently sloping dunes, and 'sat down' on a road. A tremendous cheer went up from the onlookers. They understood that they had seen the inauguration of an entirely new and unique means of transport.

It is interesting to recall the details of that first manned hovercraft, which looked very much like a flying saucer as some people visualized those mysterious messengers from space, only that there was nothing mysterious about Cockerell's creation. It had a loaded weight of 3½ tons, and through the central 'funnel' air was sucked into the system by a powerful fan. The Alvis Leonides engine provided the compressed air both for the 15-inch aircushion under the flat bottom of the craft and for

Diagram of the SRN 1 system



the two long ducts at the stern which provided the jets for propulsion; there were also two front ducts for braking and reversing. Above the rear ducts, two tall rudders had been set for steering the craft.

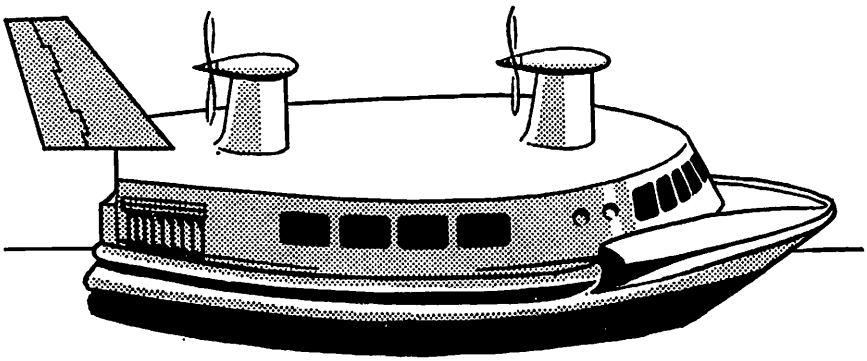
With this experimental vehicle, the Channel was crossed for the first time in July 1959—an historic occasion. In the end, the vehicle was given a place of honour for all time in Lord Montagu's Motor Museum at Beaulieu, the great collection of vintage vehicles, where it attracts the visitors as *the* vintage hovercraft.

The SRN 1 owed its existence largely to the 'National Research Development Corporation', an independent public body set up ten years earlier by an Act of Parliament with the purpose of encouraging and developing promising ideas. No doubt the hovercraft has been the first great feather in the cap of the NRDC. It is not a government department, but it can borrow money from the Treasury for promising projects if industrial backers are not forthcoming. It can also provide space and facilities for the development of a project, and this it did in 1960 to the hovercraft people—a disused naval camp with some large Nissen huts at Hythe, near Southampton, was put at their disposal. However, before they could move in they had to drive out the wild ponies that had made their home in the camp. The ponies returned reluctantly to the New Forest; perhaps they felt that it was no use trying to stand in the way of technical progress.

The NRDC also took a hand in protecting the invention all over the world—a rather costly affair; Cockerell himself could not have afforded all the overseas patent fees. Within a few hours of his first visit to the offices of the NRDC, the patent agents received their instructions. That first visit, by the way, had given a vivid picture of the inventor's quiet efficiency to the officials: he arrived with a faultlessly typed brief, lavishly illustrated with graphs, plus his film of the model in operation. And just in case the NRDC had no projector, he had brought this along as well!

The SRN 1, despite the sensation it created, had of course its limitations. At first, it could not negotiate waves of more than 1½ ft or land obstacles of more than 6–9 ins. Further development was obviously required; one by one, British manufacturers acquired licences to design aircushion vehicles for various purposes and in various sizes. Westland Aircraft, which had incorporated the Saunders Roe group, took over the experimental and development work on the SRN 1; the first major improvement was the 'flexible skirt'. Using a curtain of air alone to clear higher waves and obstacles would have been too expensive and uneconomical; so the Westland engineers had the idea of using a flexible material such as the plastic PVC or some rubber-coated fabric, as 'extensions' of the simple air nozzles at the bottom of the craft. Each nozzle now pumped its output of compressed air into one of the many 'compartments' of a four-foot-

deep flexible skirt, which gave the craft a clearance height—or 'hover-height'—of 4–5 feet. At the same time, the skirt prevented the awkward ring of spray around the craft. The saving in lift power proved to be very considerable, so demonstrating that an increase in power and size was not the only way of achieving better obstacle clearance.

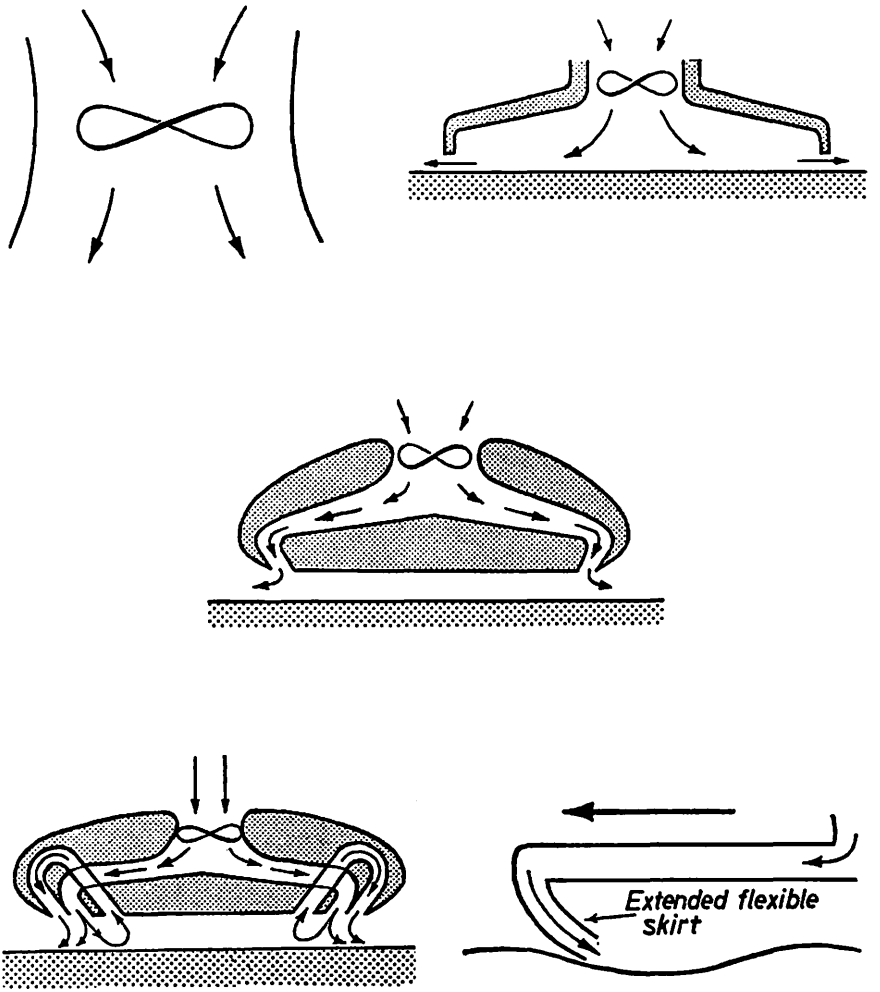


The SRN 2 (1962)

The next development craft, the SRN 2, incorporated the results of nearly three years of experimental work. Launched early in 1962, it was capable of carrying sixty-eight passengers at a speed of 70 knots; the skirt was supplied with air by two large fans, and forward propulsion was provided by two propeller engines mounted on the roof of the large cabin. For the first time, this hovercraft was used as a public transport vehicle by providing a regular trial service between the mainland and the Isle of Wight across the Solent.

By now the enormous and exciting possibilities of the new means of transport had been shown beyond any doubt, and in many countries projects and ideas were being pursued full speed ahead. No intricate calculations were required to understand that the aircushion principle had done away with that great barrier to speed at sea—the water itself, which is 800 times heavier than air and therefore so much harder to push through. During its one and a half centuries of intensive development, the power-driven ship has only doubled its speed while the railway train has increased it sixfold since Stephenson's days. The reason is that a vessel that has to plough its way through water remains efficient and economical only if it does not go too fast, and even the most streamlined hulls cannot alter that fact. Thirty knots are now accepted as the upper limit of efficiency; as soon as the speed of a ship is pushed up to forty, that efficiency vanishes because the required power is too great to be economical.

The hovercraft, however, separated from the water by its aircushion, is 'free as air' in the literal sense, and it is mainly air friction that affects its



Some hovercraft systems: (top) the ducted fan; the 'open plenum', which is a simple open box under the vehicle; (centre) the 'curtain' system; (bottom) the recirculation curtain system, which is costly to instal but works economically; and the 'impact-actuated' flexible skirt which automatically adjusts itself to the formation of waves by extending or retracting

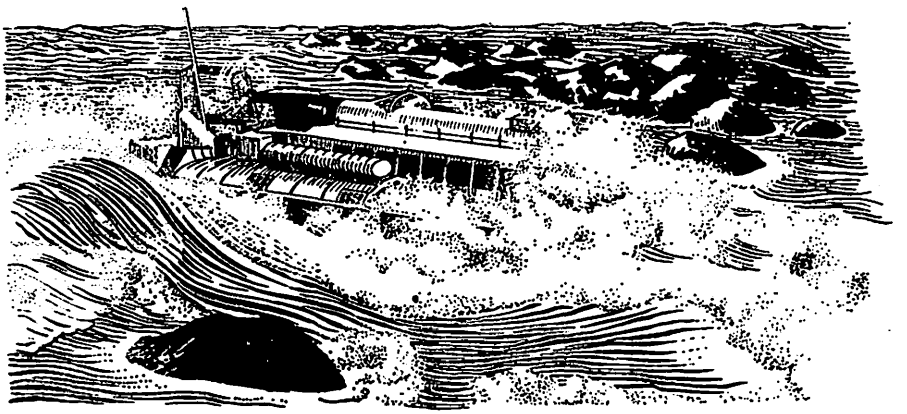
speed; the hydrodynamic drag arising from the flexible skirt skimming over the water is no great problem.

But the usefulness of the air-cushion vehicle is by no means limited to its role as a water craft. We shall now try to give an idea of the vast range of projects and possibilities that Sir Christopher Cockerell's invention has opened up.

3 What the Hovercraft Can Do

THE newspapers called it the Last Great Journey on Earth; so far as exploration of a still unknown part of our planet goes, this was certainly true of the *Geographical Magazine* expedition to Amazonas, undertaken in 1968: there is little else left to explore on the surface of the earth. But it was also a 'first'—the first major expedition made by hovercraft. And thanks to that new medium of transport, it was also one of the shortest in time; although it covered 2,000 miles, up the rivers Amazon and Orinoco, it took no more than a month.

Great was also the endurance the journey required from the hovercraft and the men on board, including a British television film team: 100 degrees Fahrenheit and 80 per cent humidity, swollen faces and insect-poisoning had to be endured. On the Rio Negro, speeds of up to 60 m.p.h. were reached. The journey included at least two brushes with death—shooting the Maipures and Atures rapids, which are among the most



'The Last Great Journey on Earth': The *Geographical Magazine* hovercraft expedition to Amazonas in 1968 included shooting some of the most dangerous rapids in the world

dangerous in the world, 'an experience which I can only compare with going over the Niagara Falls in a bus', recalled the BBC team leader. The hovercraft, controlled by two pilots and serviced by two engineers,

behaved perfectly whether on the water or on the savannah; however, drums of turbo fuel had to be deposited beforehand along the route at prearranged points.

The Amazon expedition, one of the most spectacular exploits of the new means of transport, showed the eagerness with which scientists began to use it for the exploration of the few 'blank spaces' which are still left on the world map. In the winter of 1969–70, another great hovercraft expedition—again with BBC television cameras on board—covered 5,000 miles in the heart of Africa: rivers and lakes, swamps and deserts in Mali, Nigeria, Niger, Cameroon, Chad, the Central African Republic and the Congo, ending in Kinshasa after starting out, eighty-three days earlier, from St Louis, Senegal. The journey, by an adapted SRN 6, was called 'the most audacious inland journey since Stanley navigated the Congo'. Among the nineteen people on board were scientists from Britain, France, Belgium, Norway, the United States and the Soviet Union, for apart from providing the television audiences of the world with fascinating entertainment, the trans-African expedition had the task of studying, among other things, tropical diseases such as malaria, river blindness and yellow fever.

'The notion of exploring by amphibious hovercraft has a bizarre kind of logic,' said Bob Saunders, the BBC producer on board the craft. 'It actually flies above the surface of the ground and can cross almost any terrain. . . . This latest trek by hovercraft was no less exciting than the Amazonas expedition. For all its cities and winds of change, Africa still has vast areas as fickle as they were a century ago.'

The film they brought back showed what unexpected hazards and obstacles, pleasures and surprises they encountered. The Nigerian civil war forced them to make a wide detour through Dahomey. At Gaya in the Republic of Niger, formerly part of the French colonial empire, a road bridge over the Niger river made the hovercraft stop in its tracks. The French had built it deliberately low to prevent trade between their own colony and the British one of Nigeria, so that the produce of their area would remain in French hands. But it takes more than a badly built bridge to keep a hovercraft out—it just went overland round the end of the bridge and back onto the river.

'The reaction of people in the towns and villages along the way must have been like the first sight of the aeroplane,' said Bob Saunders. 'Each time the pilot heaved his machine out of the water in an explosion of spray and dust, they turned to stare in awe and started cheering.'

At Kayes on the Senegal river, the expedition found Africa's hottest place. Here the hovercraft had to be dismantled and transported 300 miles overland to the Niger river. Dismantling the craft took four days; there were, of course, no cranes or special tools for the job, so it had to be done

by raising the sections on blocks as the pyramid-builders had done five thousand years ago.

So far, the south-eastern part of Lake Chad had remained almost unknown; powered boats were unable to cross it because it is either too shallow, or underwater plants would have fouled the propellers. But the hovercraft had no difficulty in exploring these unknown parts of the lake at great speed.

'We achieved our goal,' said Bob Saunders, 'and broke all records for the longest hovercraft journey ever undertaken. But we shall be remembered not for our skill as explorers but for the magnificence of our machine.'

Among transport engineers, the hovercraft idea caught on quickly. New designs and models were springing up everywhere, all of them based on licences acquired from the British Hovercraft Corporation, which now included the Saunders Roe company. Perhaps the most impressive of these early craft was the SRN 4, with its 165 tons and a length of 130 feet, capable of transporting up to 800 passengers at speeds of 70 knots (nearly 140 km/h.). The old calculations regarding size, power, speed and efficiency in a ship no longer apply to the hovercraft; here, efficiency increases in direct proportion to power and size. To be precise: if you double the effective diameter of your craft and double your installed power, you can lift four times the load and still keep the same hover-height. Much of the air pushed down from the bottom of the craft rebounds and appreciably augments the upward thrust of the air, which leads to considerable economy. This means that the larger the hovercraft, the less power per passenger is needed, and the less it costs to transport him over any given distance. Therefore, the SRN 4, as the first of the really big hovercraft, signified the radical break with marine engineering: this new means of transport was no longer a 'kind of ship'—it had to be designed according to completely different principles.

One of the basic facts of 'hovering', for instance, is the so-called ground effect. It is a phenomenon well known to aircraft and particularly helicopter pilots. The force of the air compressed between the aircraft and the ground, especially at touchdown—you can observe it when you see a light aircraft landing as it seems to float over the runway—helps to support the craft a foot or so over the ground. As a result, the power needed to keep a helicopter just clear of the ground is only something like a quarter of that needed to hold it higher up in the air. It is that ground effect from which the hovercraft, with its hover-height of only a few feet, benefits enormously in economy and efficiency.

Every hovercraft model designed since the early 1960's has a skirt to contain the air under the craft; it has been found that the craft can

negotiate obstacles—from waves to boulders—almost as high as the skirt. For instance, a craft with only 1 foot ground clearance can skim over 3-foot obstacles with a 4-foot-deep skirt. The material used for the skirt, which is made up of many single segments, is of the greatest importance because it must be extremely strong to withstand the strain of high-speed travel, and it must be lightweight and supple so that it deflects easily around any object in the path of the craft. A variety of fabrics, woven or knitted, have been developed and adopted, but the airtight and watertight coating is no less important; plastic coatings such as polystyrene, neoprene or polyurethane are among the most suitable. The 'life' of a segmented skirt should ideally be something like a thousand hours of travel.

Propulsion is no problem. Most hovercraft types use ordinary, large airscrews—one to four, or even more in larger craft—for moving the hovercraft forward; the SRN 4 type of large craft needs four diesel engines of 3,400 shp maximum power, plus two gas turbines as auxiliary engines, for the integrated drive of the four lift fans and propellers. Some designs have jet propulsion instead of propellers; compressed air and/or burnt gases are thrust out of large ducts, acting against fins which serve as rudders. Smaller versions of this type often have only one engine for propulsion and lift.

There is no standardized set of controls yet in hovercraft operation. You will find steering-wheels as in a ship or motor-car, or 'joysticks' as in smaller aircraft, or foot-operated rudder bars. The actual steering is frequently done by changing the propeller angle; the propellers pivot on pylons which can alter their horizontal position by up to 70 degrees. At the same time, the rudder bar changes the pitch of the propellers, altering the angle at which they attack the air. Most hovercraft types have large fins on the stern; in the more advanced designs these are not controlled manually by the pilot but automatically by a computer, which sets them at the correct angle according to the positions of the propeller pylons. The actual fin movements are carried out by hydraulic jacks. Other controls act on the fans which supply the compressed air, and on the air-filled skirt to achieve banking.

It is surprising how many controls you can find even in a comparatively simple, medium-sized hovercraft, say the SRN 6, a craft popular for short-distance ferry service (also the type adapted for use in the record-breaking 1969–70 expedition through Central Africa). Although it carries fewer than forty passengers, and has only one engine, one propeller and one lift fan, its control cabin looks very much like the cockpit of an aeroplane. There are a central steering column, a lever controlling the propeller pitch, a fuel throttle controlling the engine speed; also two rows of switches for the electric and hydraulic systems and the gyro compass, and half a dozen or more dials for indicating various conditions, from fuel

level to air speed. The rudder bar acts not only on the two stern rudder fins (this craft does not need a computer), but also retracts part of the skirt for banking when the craft turns. Ballast can be pumped fore or aft according to starting or landing requirements, or to keep the craft from pitching too much in a rough sea. Yawing can, to some extent, be corrected by rudder movement and rolling by lifting the 'hems' of the skirt on either side.

These are the operational controls as they have evolved together with the hovercraft itself. As types grow bigger, manual control is bound to be reduced, with a correspondent increase in automatic operation and computerization as in ocean-going ships and airliners.

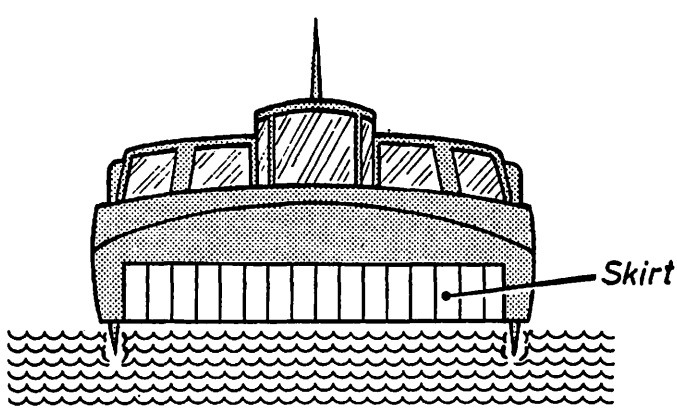
Hovercraft—or cushioncraft, as some technicians prefer to call them—are today being built, developed and commercially used all over the world and have already superseded conventional 'displacement' craft, meaning ships, for several purposes because they are faster, more economical to run, and can be used as amphibious means of transport which need no expensive port installations. The Americans and the Japanese were the first to acquire British licences as far back as 1962, and the Russians were also quick off the mark to create their own designs; Britain, however, has still the greatest number of development units turning out types for a large variety of purposes.

The first regular passenger-carrying service, with the 9-ton SRN 6, started across the Solent in 1965 and has been in continuous operation ever since. This type, used by several ferry operators, seats 38 people, runs at 56 knots (105 km/h.), and needs as terminals only two very simply prepared beaches. In 1967, the passengers aboard the Cunard cruise-liner *Sylvania* enjoyed the special treat of hovercraft excursions: an SRN 6 had been taken on board and was used *en route* to offer pleasure trips to the passengers. In the same year, two SRN 6's started a service connecting Naples with the islands of Ischia and Capri, and another two turned up at the EXPO 67 in Montreal. As a result, the Canadian coast-guard service bought a high-performance craft of this type, while the Iranian Navy ordered ten of them. Predictably, a film company hired a hovercraft to incorporate it in the plot of an exotic thriller. A year later, the British armed forces formed their first hovercraft units, a Royal Transport Corps Hovercraft Squadron—going into operational exercises with four craft off the Malaysian coast—and the Royal Navy Hovercraft Unit, which took their first craft to the Falkland Islands in the South Atlantic. An important part of the unit's task was to test the performance of the craft in extreme conditions and well out of range of the manufacturer's spare-part service during a programme of exercises lasting twelve months.

The small, extremely fast SRN 5, of which a number of craft were coming off the production line after 1968, showed the truly amphibious characteristics of the new vehicle in various novel applications. It has been on trial in the Arctic wastes of Northern Canada, proving that a hovercraft can go where nothing else can—and at 50 knots into the bargain! It negotiated the Mackenzie River during the break-up of the winter ice, where it had to pull itself off the ice within seconds after a below-zero night; it has crossed the torrid Libyan desert over rocks and thorn-infested terrain at speeds unthinkable for any other means of transport apart from the aeroplane; it has served as river ambulance, harbour fire-tender, and on smuggler patrol in South-east Asia. Equipped with American gas turbines it has been in operation with the U.S. army.

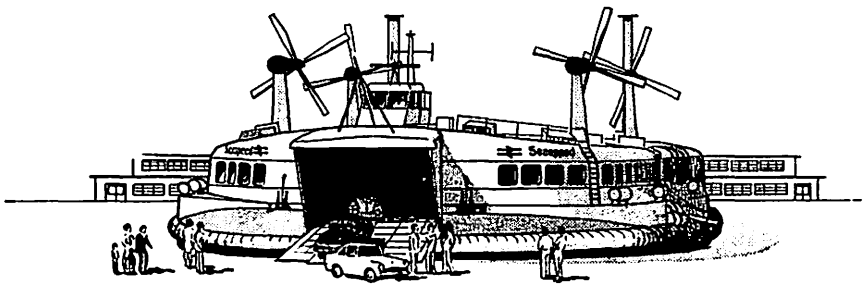
Where the hovercraft is not required to move over land, greater economy can be achieved by rigid sidewalls instead of flexible skirts: the hull extends down into the water to form an effective 'curtain' which prevents air leak, and as a result the power required to generate and maintain the air cushion is much lower. This type, as developed by Hovermarine as a 60-passenger craft, works with water-screws for forward propulsion, and with sea-rudders for steering control. The Vosper-Thornycroft VT 1, prototype of a new commercial craft, is semi-amphibious: over the water it lifts itself above the surface except for its water-screws, rudders and skegs (small keels), but on approaching the shore it noses up the beach, unloads and loads, and then withdraws back into the sea by means of its own water-screws.

Naturally, the installation of regular cross-Channel services for passengers and cars was one of the first achievements of the hovercraft age.



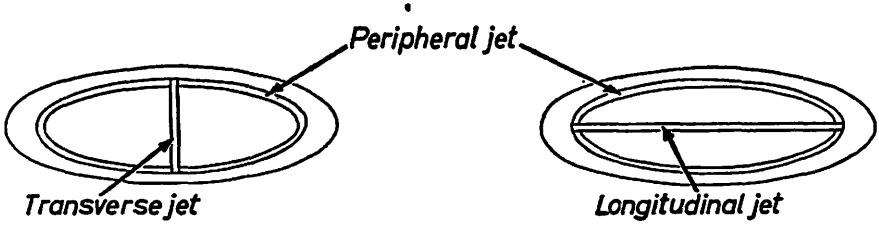
Rigid-sidewall hovercraft like this Hovermarine HM 2 are more economical than the flexible-skirted models, but can only move on water

British and Swedish companies started these services between the Dover–Ramsgate and Calais–Boulogne regions in the mid-1960's; here, the Mountbatten class SRN 4, which can accommodate over 250 passengers

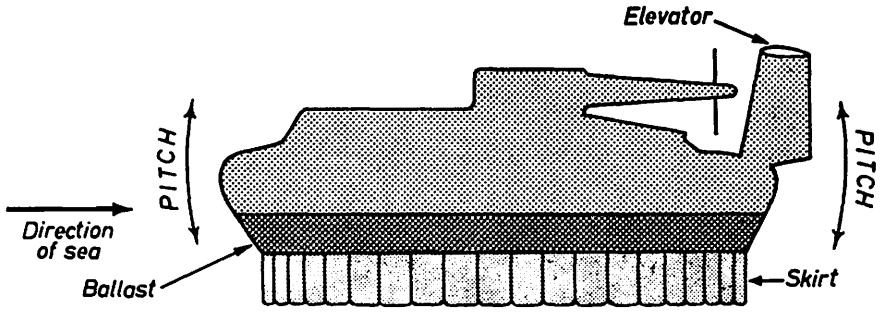


A new scene in cross-Channel transport, but already familiar to hundreds of thousands of travellers: a passenger-car hoverferry at its terminal

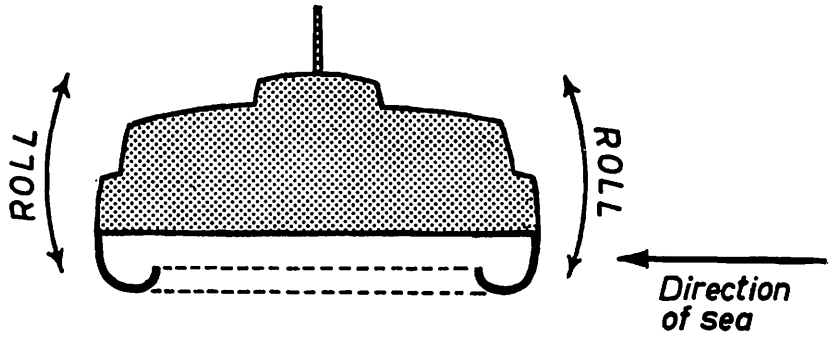
and 30 cars, dominates the scene. Designed for all-year-round service, this 165-ton craft with its overall length of 130 feet makes the crossing, for which the conventional boats need at least 90 minutes, in about a quarter of the time if the weather is not too unkind, at a cruising speed of 55–65 knots in 4–5 feet seas and of 20–40 knots in 8–10 feet seas. The Mountbatten has four airscrews, driven by gas turbines, and a light-alloy body designed very much like that of an airliner. The great advantage is, of course, that of speed; although even a large hovercraft such as this tends to be bumpy in heavy seas, many travellers prefer to be seasick for only half an hour instead of for one and a half hours as they would on a conventional boat. The fares are about the same in both cases, but on the rigid-sidewall HM 2, with its marine diesel-engines and water-screws, they are lower.



Hovercraft can be made stable in pitch and roll by various systems, such as a 'compartmented' aircushion; this splits the base of the craft into separate areas which can be fed with variable air supply. There is a constant peripheral air jet, but the transverse jet (left) counteracts pitch and the longitudinal one (right) counteracts roll when this is necessary



Another system for correcting pitch is by movements of the elevator and ballast



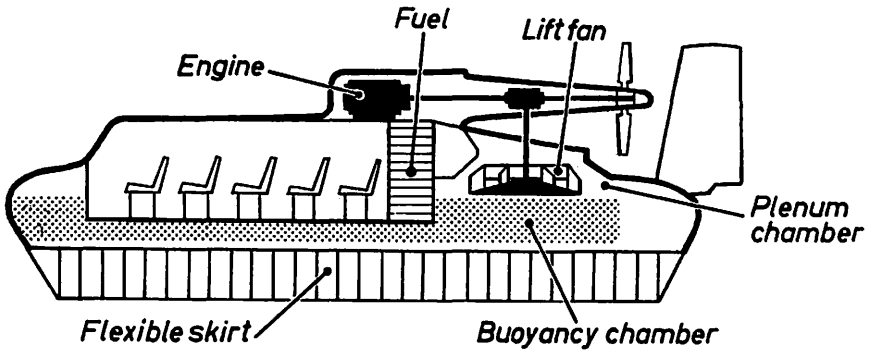
Roll can also be counteracted by lifting the sides of the skirt independently.

This Hovermarine type, specially equipped with Decca instruments, has also proved its worth as a high-speed hydrographic survey craft in East Pakistan, where the development of shipping channels is of major economic importance. Operating on a pre-set programme at a speed of 30 knots, the HM 2 makes it possible to record automatically exact particulars as to water depth and channel width, the latter within an accuracy of one yard. The instruments on board take their automatic bearings from radio impulses sent out by transmitters on land; the range of the hovercraft is some 400 miles, and due to its speed it can return to port quickly over long distances with its tape-recorded material. As its route is automatically controlled, it needs only a crew of four.

At the very end of the range of hovercraft models are the two smallest ones, the Hoverhornet and the Hoverhawk. Early in 1960, the British Hover-Air company sold 3,000 of them to the U.S. and Canada. The Hoverhornet is a one-man craft, 8 feet long, which costs much less than a small car and can be carried on a car roof-rack; the two-seater Hoverhawk is 15 feet long and is mainly being used in Canada for fishing, wild-

fowling, snow sports, hunting and 'executive' transport. Both light models can move at 35–45 m.p.h. over rough ground, water, snow, and ice.

The French have always been experimenting with new kinds of vehicles, and were among the first countries to acquire hovercraft licences. The *Société Bertin* succeeded in getting government help for development, and produced several designs of what it called the 'aero-slide' in co-operation with the General Transatlantic Company, which owns and runs the big



The SRN 5 and 6 models have an integrated power system for lift and thrust

Atlantic liners. The types include a small amphibian craft for airport control and the large Naviplane N.300, with two propellers but four lift fans; both types can reach 100 km/h. But the project on which the French hovercraft engineers are spending most of their time is the *aérotrain*. We shall return to it later in connection with all the other tracked hovercraft designs that are being developed as tomorrow's means of transport.

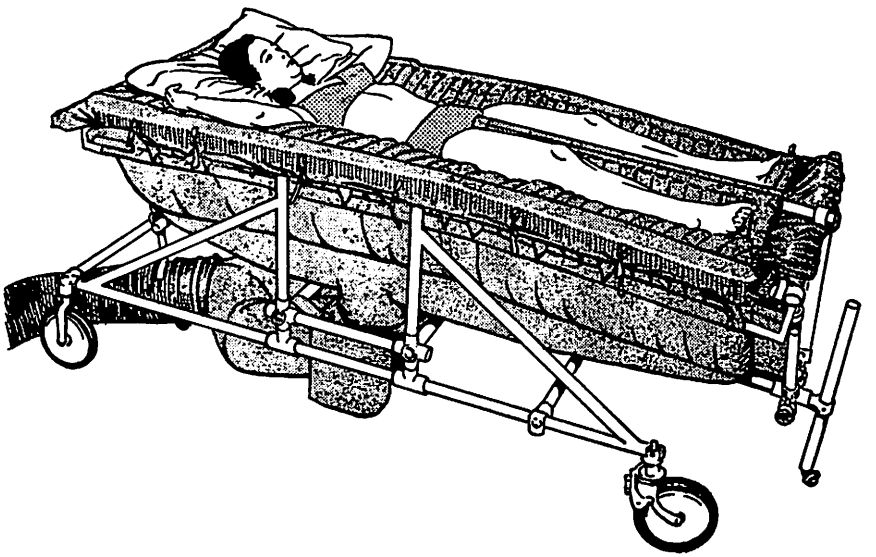
The success of the hovercraft has, of course, inspired other inventors to design new kinds of vehicles on similar lines. An interesting development is the 'Pneumatic Hydrocraft', as it was named by its creator, Commander Basil Hurle-Hobbs—or 'bubble craft', as the onlookers called it when it was first tried out in Chichester harbour, Sussex, in 1970. This prototype, seating 14 passengers and capable of reaching 53 mph, skimmed over the water on a thin film of air bubbles forced along the outside of its hull, thus making the 'conventional' hovercraft skirt unnecessary.

Is the hovercraft a safe means of transport? The question was asked when, in March 1972, a 38-seater SRN 6 overturned in rough seas and a gale on its way across the Solent, with the loss of four lives. It was the first serious hovercraft accident. Experts examining it came to the conclusion that there was nothing wrong with the craft; in such heavy weather any ship of that size could have come to grief.

4 The Invisible Cushion

THERE are few examples in technical history of such unexpected applications of a new principle as in the case of the hovercraft—or rather of the aircushion technique. Take, for instance, the 'hoverbed'.

In 1967, a report by one engineer and three doctors in the British medical journal *The Lancet* described a revolutionary treatment of two patients who had suffered severe burns. One patient had petrol burns over one-third of his body, front and back; the other had been burning waste paper in a gale force wind when his oily clothes caught fire and he received burns on his right side. Both were put on the hoverbed for a number of hours, and recovered rapidly by means of levitation—the support of a body without visible means or, as one might put it, on an invisible cushion. This makes it possible for the affected areas, which produce moisture where the skin has been burnt off, to dry out quickly, and a new skin will be formed within a day or two where nothing but air touches the body. The danger of septic poisoning, always present in cases of severe burns, is reduced, the pain is lessened, and the symptoms usually accompanying the condition, such as shivering and vomiting, do not appear.

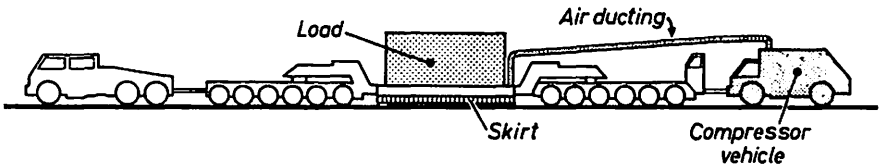


The hoverbed for treating burns

How is this achieved? The hoverbed, or burns bed, consists of a rigid framework inside which there hangs a bag of light nylon fabric coated with the kind of proofing one uses for anoraks or macintoshes. The top of the bag consists of two rows of pockets very much like the skirt segments of a hovercraft. Warm, sterile air at ¼ to ⅓ lb. per square inch is pumped into the bag and inflates the pockets. When the patient is put on the bed, the pockets form a seal along the side of his body, and fall away beneath it; thus the body is left supported solely by air, only the head rests on a pillow. The seal conforms automatically to the body shape of the patient and follows any of his movements.

The invention of the hoverbed was a remarkable example of collaboration between doctors, engineers, industrial companies and authorities in Britain, including two ministries, the Medical Research Council, a textile concern and the hovercraft people; no fewer than fifty industrial firms helped with supplying materials and components. The aircushion bed required a great deal of technical development, particularly its motor and fan, which were at first rather noisy and irritated the patient. The noise of the machinery, which supplies 450 cubic feet of compressed air per minute, was eventually brought down to a tolerable level. The bed is also extensively used in geriatric wards, that is for old people who are bedridden and suffer from bed sores—which can be cured or relieved by regular spells on the invisible cushion.

The first industrial application of the aircushion principle was the heavy-load transporter. It is designed to spread the load when moving, for instance, giant electrical transformers weighing 200 tons or more; this

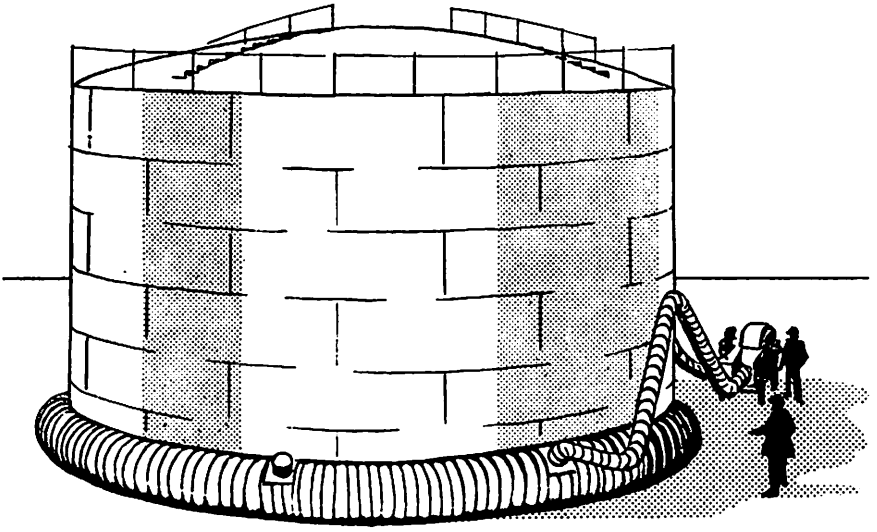


Giant road transporter for moving very heavy loads on an air-cushion.

avoids the necessity of strengthening bridges on the route. The whole outfit is almost a train, with the hover-platform carrying the transformer in the centre, flanked by a six-axle chassis on either side, with a compressor vehicle bringing up the rear. This provides the skirted platform with something like 7 lb. pressure per square inch, giving about 2 inches ground clearance. A tractor in front pulls the 'train' along.

Perhaps the most spectacular aircushion transport operation ever carried out was the moving of two oil-storage tanks at Manchester in 1967.

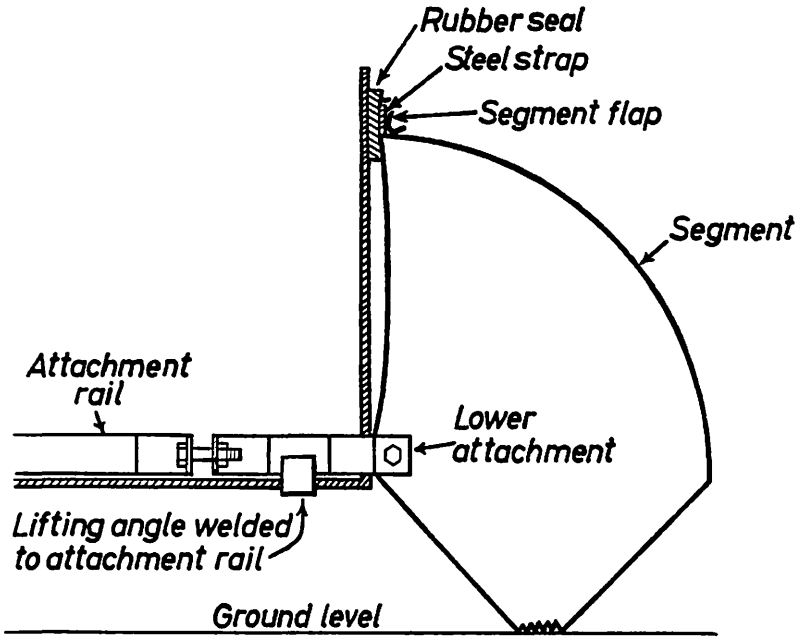
The tanks, each 50 feet in diameter and weighing 70 tons, had to be moved 200 yards to a new site. The Hovercraft Development unit provided tailor-made skirts which were strapped around the base of the tanks, and air was pumped in at only 60 lb. per square foot, sufficient for raising the tanks seven inches off the ground.



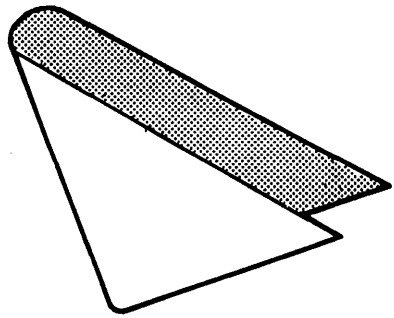
Shifting a 70-ton oil tank over 200 yards by means of a hoverskirt

Since then, the two trends of development in airlifting equipment have been clearly marked: high-pressure platforms for moving heavy loads by creating an aircushion of only a few inches thickness, and low-pressure pads and pallets, often with no more than 1½ lb. pressure per square inch, for carrying smaller loads in goods yards, warehouses or ships' holds, but with a lift capacity of up to 8 inches, enough to lift loads over railway lines and similar obstacles. Special platforms have been designed to give more than 20 inches lift height for loads of up to five tons on farms and building sites, or for instance for transporting oil-drilling equipment over peat soil in Alaska.

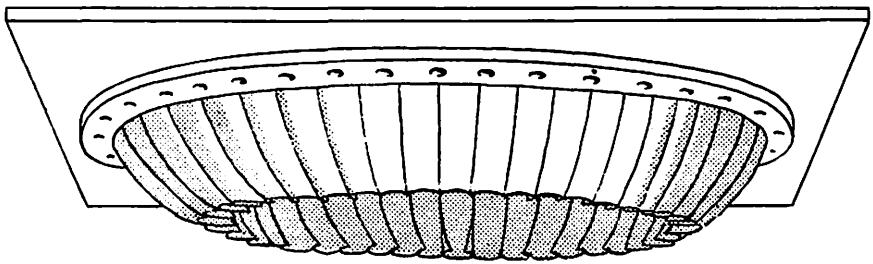
The variety of industrial jobs which the aircushion can do is amazing, and especially in America new uses are being introduced almost every week. Boeing airliners have been given aircushion turntables and lift pads under their nose wheels for quicker and easier shunting on the airport runways; heavy cruisers are being moved into position in exhibition halls by means of 'aero-castors', and tractors over indoor floors on airfilm.



How the hoverskirt is attached to an oil tank for shifting

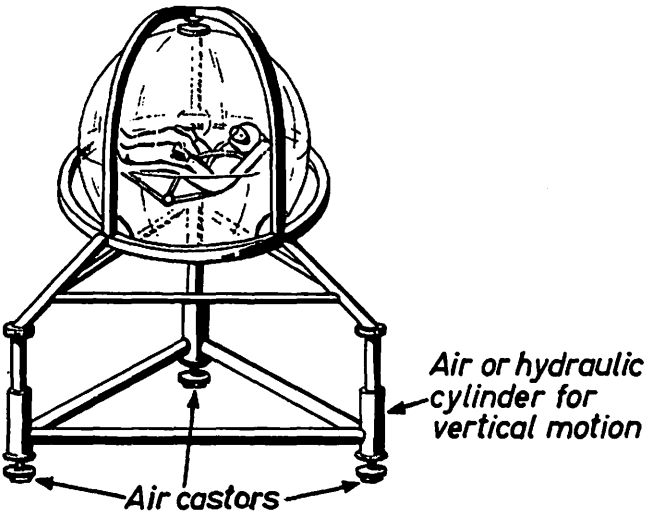


Segment of a hoverskirt for moving heavy loads



This is what the underside of the segmented skirt of a hover-pallet looks like

Astronaut training equipment is shifted on small air-pads, and space chambers are moved on air-castors. In the home, dishwashers have been fitted with air-pads to prevent breakage of crockery; air-castor devices for moving refrigerators can be operated by ordinary vacuum cleaners (from the blower end, of course). In fact, wheels are being replaced by air-cushions for a number of moving jobs.



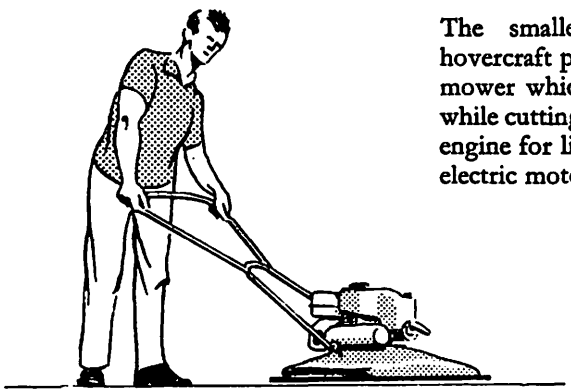
'Aero-castors' help to move this training machine for astronauts into position.

In Britain, a large number of factories have introduced air-support systems for transporting components and goods on conveyor belts. In the glass and ceramics industries, aircushion support has solved a few transport problems on the factory floor. It has been found that a 500-lb. load on a wheeled trolley needs as much power for moving as a 5,000-lb. load on an air-pallet, which has also the advantage that it can be shoved in any direction. Oddly enough, manual labour has come back in many instances as a result of the introduction of the aircushion—a worker can easily push an air-pallet with a load of 10,000 lb. or more, which would normally need a motor for pushing or pulling. This has become evident in cases where heavy office furniture and equipment had to be shifted within a factory. The shifting of delicate loads such as scientific instruments or brittle components, which might be damaged by the vibrations from a normal wheeled truck, is much safer by means of a hover-pallet. It does not have to provide more ground clearance than two inches and can get over obstacles 1½ inches high when carrying loads of up to half a ton, operating at pressures of 5 lb. per square inch. But in theory there is no limit to the weight that can be carried by appropriate aircushion equipment, while at

the other end of the scale the principles of the hoverbed are bound to be applied in future designs of ambulance beds, stretchers and orthopaedic or surgical beds; even the 'iron lung', which provides artificial respiration, may be improved by applying the aircushion principle.

An accidental discovery during military exercises with hovercraft in South-East Asia was that a 6-ton craft can cross a ricefield and leave the young shoots intact. What this means is that the job of crop-spraying can to some extent be done by hovercraft, which is much cheaper in operation than helicopters or fixed-wing aircraft, with a more accurate aim and therefore less waste as it does the spraying of insecticides or fertilizers immediately above the ground instead of from a height, where the spray is liable to be carried away by the wind.

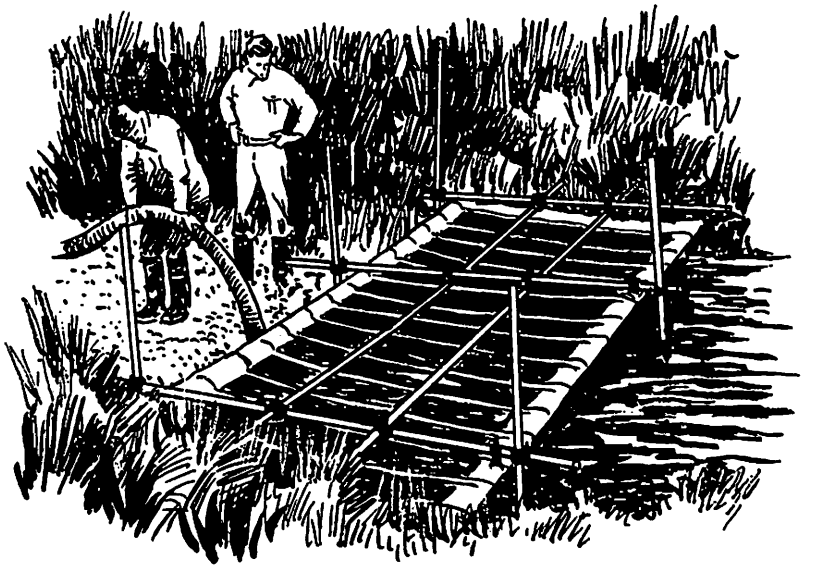
Another most promising development is the bringing in of the banana harvest in Israel by a hand-guided small hovercraft that looks like an overgrown lawn-mower. Designed by two engineering experts from the Haifa Technion, it proved its worth for the first time on the Ein-Hamifratz kibbutz in 1970. Banana harvesting is normally hampered by all kinds of snags: the trees grow outward as well as upward, leaving dead branches on the ground, and there is usually a network of irrigation sprinkler pipes so that conventional vehicles cannot be used easily—and carrying the heavy bunches on foot is a backbreaking and uneconomical job. A normal banana bunch weighs about sixty pounds, and has to be carried over hundreds of yards from the groves to the lorries waiting on the nearest



The smallest machine using the hovercraft principle—the hover lawnmower which floats on an aircushion while cutting the grass. It has a 2½ h.p. engine for lift and cutting, or a 1 kW. electric motor

road. The little hovercraft—it has, in fact, a lawn-mower petrol engine which supplies the lift fan with 6 h.p.—rides on an aircushion of 8 inches and can easily be pushed by hand. It can carry a load of 330 lb. A similar kind of hovercart can also be adapted for harvesting sugar beet in muddy ground, or to carry fodder to cattle cut off by floods or snow.

A rather unusual agricultural application of the hovercraft was tried out successfully for the first time in South-west Africa in 1967: shrimping on a tidal quicksand beach which could previously be reached only by small rowing-boats. The hovercraft was able to carry 300 lb. of shrimps at a speed of some 20 knots.



An offspring of the hovercraft skirt is the fabric cofferdam for damming waterways. It is filled with water instead of air

The hovercraft skirt principle is now frequently applied to the purpose of damming waterways. A row of skirt segments is placed across the water; the segments are inflated by filling with water to a greater depth than that in the waterway. Thus the pressure inside the segment is made greater than the outside pressure, and the segments form a seal which conforms closely to the irregular shape of the riverbed and banks. True,

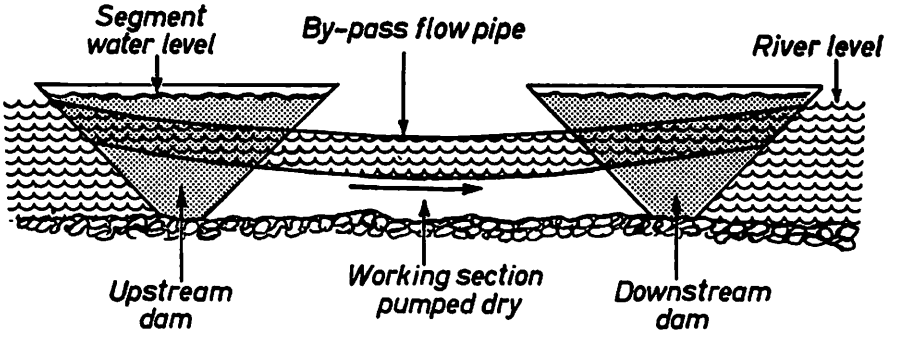


Diagram of the segmented cofferdam

there is no air-pressure involved, but it was a group of air-cushion engineers who thought of using the skirt principle in this way.

Another 'fringe' application of the new pressurized-air techniques was the U.S.A. pavilion at the EXPO 70 in Osaka, Japan; it was entirely supported by air, a structure similar to a child's balloon. Measuring 274 by 465 feet, the enclosure was the largest clear-span, air-supported roof ever built, and designed to withstand typhoons and earthquakes. The structural skin was made of a polymer plastic, and four giant blowers maintained the air pressure in the pavilion.

An Australian inventor built the first 'hoverhome' in 1970, an amphibious caravan mounted on a raft with a hoverskirt, powered and propelled by two 600 cc. engines. Designed mainly for use in swampy regions, the craft will become the temporary home for workers such as surveyors, structural engineers or scientists, permitting them to move by day while sleeping comfortably on couchettes at night; kitchen, showers and toilet are of course provided. And a British engineer has invented the hover dodg'em, the latest fairground attraction: miniature hovercars with 2-stroke engines providing a pressure of 12 lb. per square inch, with speeds up to 45 m.p.h. The rider makes the vehicle move by leaning forward, i.e. by shifting his weight, and steers it sideways with a handlebar.

However, the major impact of the hovercraft revolution will be in the field of transport, where it is bound to affect all of us who have to, or want to, travel on business or for relaxation. That revolution is still only in its first stages. Perhaps the next steps will bring us larger and larger aircushion vehicles—some engineers visualize enormous ocean-going hovercraft carrying thousands of passengers and many hundreds of cars, or freight loads of tens of thousands of tons, at twice or three times the speed of our fastest ocean liners.

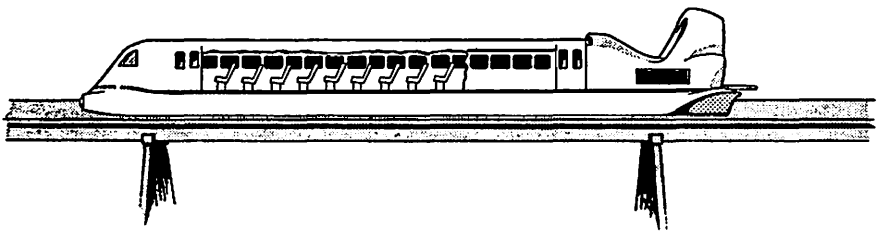
Perhaps the most advanced development project on these lines is that of one of the research centres attached to the U.S. space agency, NASA; it aims at combining the hovercraft principle with nuclear propulsion. The idea is to equip a 10,000-ton freighter craft with a water-moderated nuclear reactor for driving 6,500-hp steam turbines which provide the power for the lift fans and for propulsion. The vehicle could travel about 3 million miles before refuelling becomes necessary; it could carry its payload at the same cost as a cargo ship, but at a greatly increased speed. The designers also envisage a 2,000-ton passenger hovercraft with nuclear power, a little larger than a football field; 14 lift fans would provide an aircushion that would give it a 10-ft clearance above the water, enough for comfortable ocean travel. However, a lightweight reactor would first have to be developed.

5 Trains without Wheels

FOR a century and a half, our most important means of long-distance land transport, the railway, has remained substantially unchanged. We still travel on twin rails of the gauge introduced by George Stephenson (in fact, he chose the gauge of the old Roman wagon roads of two thousand years ago); we still have coaches pulled by locomotives, though steam has gone out of fashion for the purpose. Our fastest regular trains run at speeds a mere three times greater than the 35 m.p.h. which Stephenson's *Rocket* achieved during the victory run after winning the Rainhill competition for locomotives in 1829—compare this with the speed increase in aircraft from the Wright brothers' six miles per hour in 1903 to the 1,400 m.p.h. cruising speed of the supersonic *Concorde* seventy years later!

New ideas in rail travel have emerged from time to time in our century, such as the monorailway, but the engineers have not shown a great deal of enthusiasm for them because there seemed to be hardly any gain in economy, wear and tear, and safety, though certainly some in speed. Stephenson's elaborate calculations on friction and gravity—which made him declare that 'wheels and rails belong together like man and wife'—still hold good and rule the railway system. It is only now that we are about to break out of the old convention.

France, Britain and America are working full-speed at bringing that revolution about, with the French in the lead. Railway enthusiasts as they are, they have taken the idea of the 'tracked hovercraft' to their hearts, calling it the *aérotrain*—a term which may be adopted also by the English-speaking world. Already in 1965 the French government decided to participate, to the tune of 3 million francs, in the aerotrain programme of the big Bertin company. A half-scale test track and two trains were built; the 'rail' has the shape of an inverted T over which the train glides,

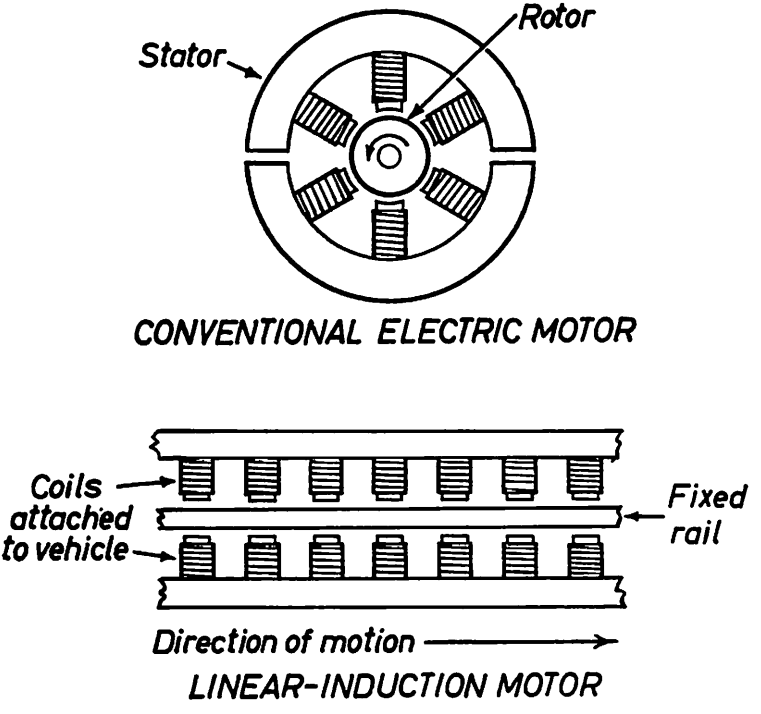


Model of the French inter-city *aérotrain* for linking Paris and Orléans

without wheels, on its aircushion. Originally, propulsion was to be effected by a large airscrew, powered by a gas turbine or diesel engine, towering over the rear of the train; but it turned out that to reach the desired speed of 200 m.p.h., it had to be boosted by a rocket engine. So the French adopted the new British linear-induction motor, which seems to be the ideal power unit for trains without wheels.

Its inventor is Professor Eric Laithwaite, of the Imperial College, London. It has no rotating parts but consists of a series of bar magnets, each some 40 inches long in a coil—as it were, the 'stator' of a conventional electric motor, but unrolled flat; the magnets react against an electric rail playing the part of the 'rotor' (only a very light one is needed as it has no weight to carry). The 'stator' is pulled forward—together with the train underneath which it is situated. The linear-induction motor has none of the limitations of a rotary one, and can therefore move a train at much higher speeds; 300 m.p.h. or more may be the top speed at which a tracked hovercraft can safely operate.

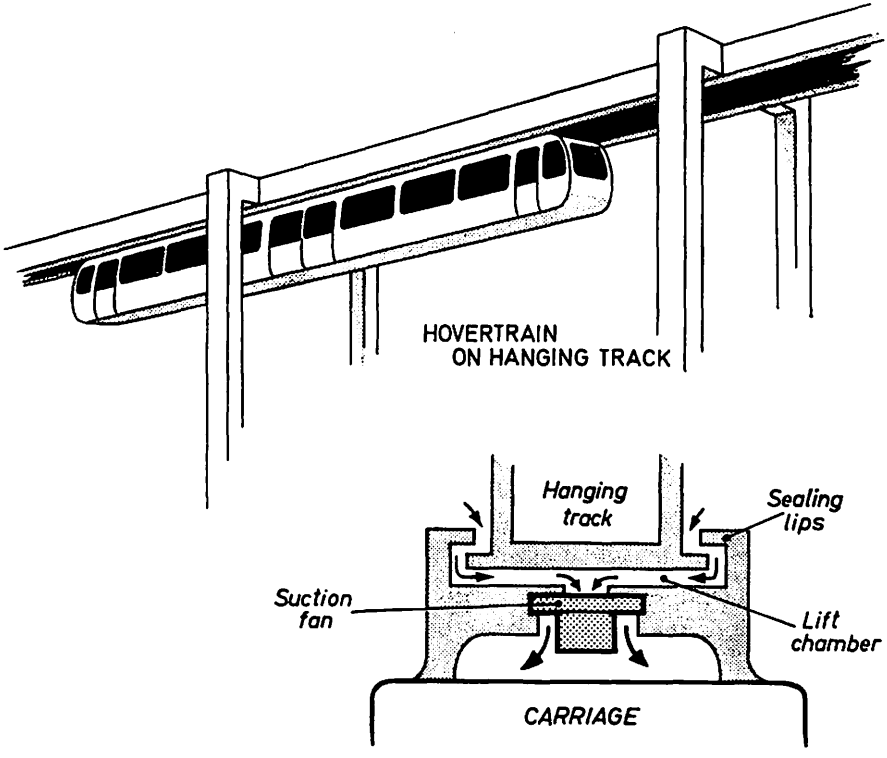
France's first full-scale 80-passenger aerotrain will link Paris and Orléans over a distance of 65 miles at a cruising speed of 155 m.p.h. The



The new linear-induction motor compared to the conventional electric motor

front coach—one can no longer speak of a locomotive—has a driver's cabin, though the driver himself may be no more than an observer in a fully automatic system. Still, there are two engines, but only for providing the aircushion; they are installed in the rear part of the articulated train. The aircushion, which has the form of an inverted U, fits around the centre rail underneath the coaches; it comes from a series of air-pads. There is no part of the train which has any immediate contact with the track when in motion. Other hovertrain projects in France are one linking Paris with its existing airport, Orly, and the new one being built at Roissy; an inter-city route Paris–Le Havre; and a link between Marseilles and its airport.

The Bertin system, however, is not the only tracked hovercraft scheme in France. Its rival is Professor Maurice Barthalon's 'Urba 8', also subsidized by the government. It is, in a way, an inverted aerotrain: the coaches hang from an overhead track, supported by an air film sucked between the track and a vacuum chamber on the roof of each coach; basically, it is therefore a suspension railway, but without wheels. It is also powered by the linear-induction motor. The first Urba line, completed in



This is what the French overhead hovertrain looks like and how it works

1970, runs for two miles along the Rhône near Lyons, connecting the city centre with the site of the International Fair; it cost about £1 million per mile—much less than an underground line. The top speed of the Urba trains has not yet been worked out. The system may have special advantages in connecting town centres with airports.

America's major tracked hovercraft project is being developed by the Transportation Systems Division of the General Electric Company in conjunction with the U.S. Department of Transportation, which provided much of the finance to build a research vehicle; the aim is to open the first passenger service in 1975 'to meet the greatly increased inter-city transportation needs of tomorrow' and to provide links with the airport at speeds of up to 300 m.p.h. The highly streamlined one-coach train, weighing 40,000 lb. fully loaded, is 53 feet long; it is supported by four aircushions only about half an inch above a channel-shaped guideway, and four additional aircushions keep the vehicle away from the sidewalls of the guideway. Here, too, experiments began with aircraft-type turboprop engines but were continued with the linear-induction motor which seems so eminently suited to the purpose because it makes no noise and produces no air pollution—two important points where transport is planned from city centre to city centre.

High-speed guideways for tracked hovercraft will have to be straighter and more even than ordinary railways because at 300 m.p.h. the effect on the passengers of a hill-and-dale ride with curves would be that of a funfair switchback. In fact, human guinea-pigs have been subjected to test rides to observe their reactions to seeing the extremely rapid movements of trees and buildings past the windows. We still know very little of the visual effect on people looking at near-distance stationary objects from a vehicle moving at five or six times the speed of a motor-car. Presumably they will get used to it easily, just like the first railway passengers who had been warned that at speeds of more than ten miles per hour a human being would simply go mad.

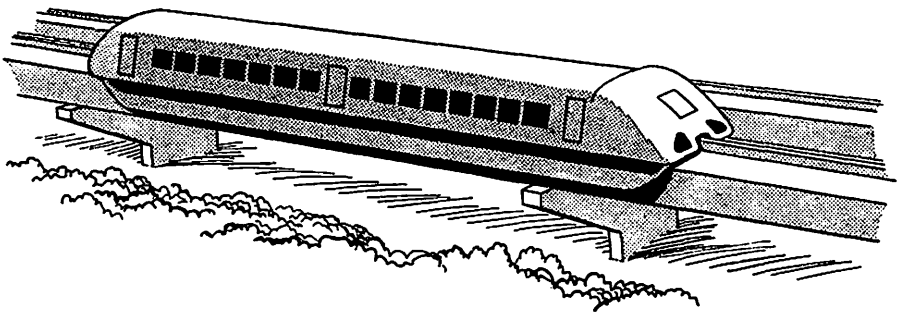
There are, of course, rival American hovertrain systems. One of them suggests giant steel tubes in which missile-shaped trains, 195 feet long, would carry 100 passengers at 400 m.p.h.; the trains would be kept floating in the centre of the tube by six large air-pads, three fore and three aft, pushed along by a turbo-propeller at the rear.

Then there is the 'levacar' project of the Ford company. It has a series of lift pads at a much higher pressure than is usual in hovercraft, but the air clearance is extremely small—no more than a film of air between the vehicle and the track.

In Switzerland, Carl Weiland, a private inventor, developed what he called the 'labyrinth seal' for tracked aircushion vehicles. It is a rather complicated system of shunting the compressed air through a series of 3–4

internal passages before it is allowed to escape; separately driven propellers re-energize the air in each passage. Although it is a costly installation, it may save up to 40 per cent of power.

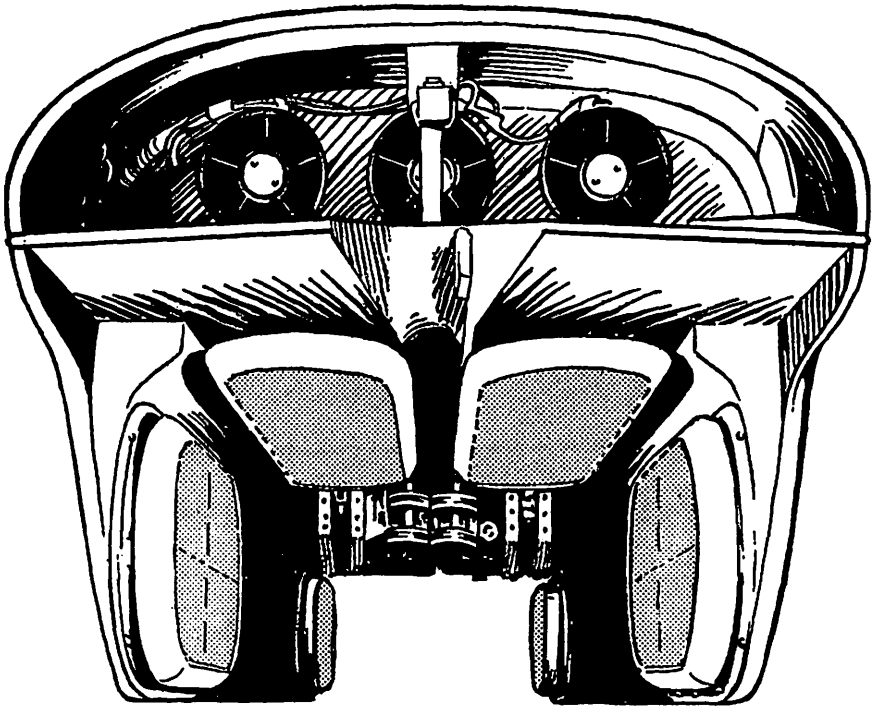
The British tracked hovercraft project is perhaps, from various points of view, the most interesting one. It goes all out for beating air transport timewise in inter-city travel, and intends to provide high-speed links between towns and airports so that, for instance, London's new airport in the Thames estuary will be reached faster from the city centre than the existing Heathrow site with its coach service ferrying passengers through the crowded streets of the metropolis. After preliminary studies and experiments with small-scale models at the Hovercraft Development laboratories at Hythe, near Southampton, a new research centre for eighty scientists and engineers with a 25-mile stretch of land for a test track began its work at Earith, Huntingdon, in 1970. The track consists of twin 'rails', one for each direction of travel, so that the effect of passing trains can be observed. The trains are designed to



Britain's 300-m.p.h. hovertrain on its test track near Cambridge

reach speeds of up to 300 m.p.h., propelled by linear-induction motors; the vehicles are about 50 feet long and 10 feet wide. They are supported around the track—of the inverted-T type—by aircushions which are contained by Cockerell's peripheral jets; they provide lift (by pushing against the track from above) and guidance (by pushing against the centre rail of the track from both sides).

The task of the research team is to collect data on the performance of the linear motor, on the aerodynamic forces involved in 300-m.p.h. travel, on suspension, power consumption and the possible effects of track irregularities. The most typical English feature of the whole research establishment is that it collaborates with the local organizations for nature conservancy—because the scientists and engineers want to disturb wildlife in the test track area as little as possible.



Underside of the British tracked hovercraft with its air-pads on three sides of the rail and the linear-induction motor and fans above them

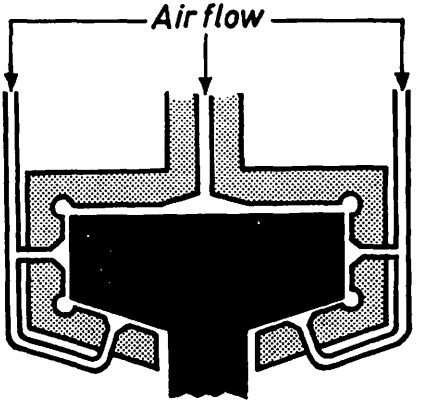
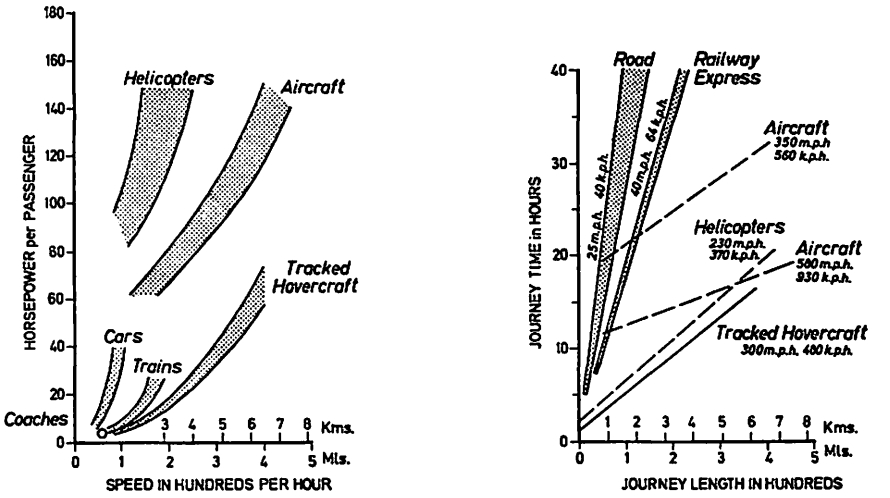


Diagram of an alternative system for keeping the hovertrain on its guide rail

Among the first projects being studied here are a tracked hovercraft link between London and Manchester and a 30-mile link between the airports at Heathrow and Gatwick. The U.S. Department of Transportation, which had carried out a comparative study of American, French and British hovercraft designs, came to the conclusion that the latter is the cheapest, and it may authorize a $2,000-million inter-city transport system based on the British system. Germany, too, is interested in it and may build a 600-mile high-capacity rapid transit system under British licence, linking Hamburg, Frankfurt and Munich.

Are we, then, going to see the old railways, one by one, being superseded by tracked hovercraft? Chances are that the age of Stephenson's rails and railways is nearing its end, but that in its new form the permanent way will be a formidable rival of the short-haul aircraft. The flying time from London to Glasgow, for example, may be only an hour, but it takes the traveller almost three hours from city centre to city centre. Once our present railways stations have been converted to hovertrain terminals and the rails to hovertracks, the journey would take no more than two hours. The foremost British traffic expert Professor Colin Buchanan said in 1969: 'We are dealing with something which could influence considerably the way of life and the social habits and organizations of a significant proportion of the population.'

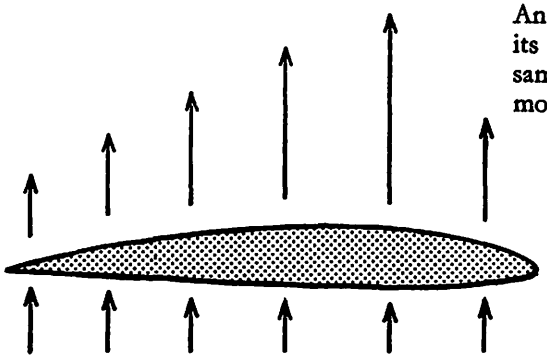


Two graphs showing the comparative performances, power requirements, speeds and journey times for various transport systems. They show that the tracked hovercraft is the most economical and the fastest one, at least over medium distances.

6 Ships with Wings

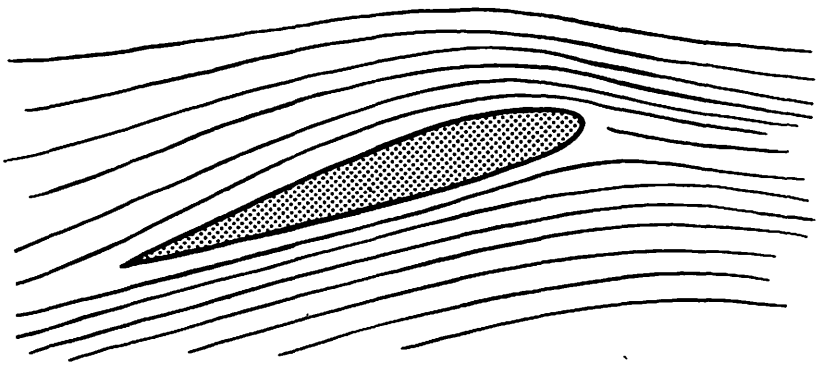
IT MAY be no coincidence that the hovercraft is not the only revolutionary means of transport that has been developed in our age; we are witnessing the emergence of new ways of thinking in the whole field of mechanically moving people and goods from place to place, from continent to continent. The hydrofoil craft is another outstanding example.

It cannot, like the hovercraft, move over land, but only over water; but it is also a skimmer, or 'boundary' vehicle. However, instead of producing its own aircushion like the hovercraft it uses the natural atmosphere to



An aircraft wing gets most of its lift from its top surface. The same applies to a wing, or foil, moving through water

A hydrofoil moving through water gets its 'dynamic lift' by being pulled along with the boat to which it is attached

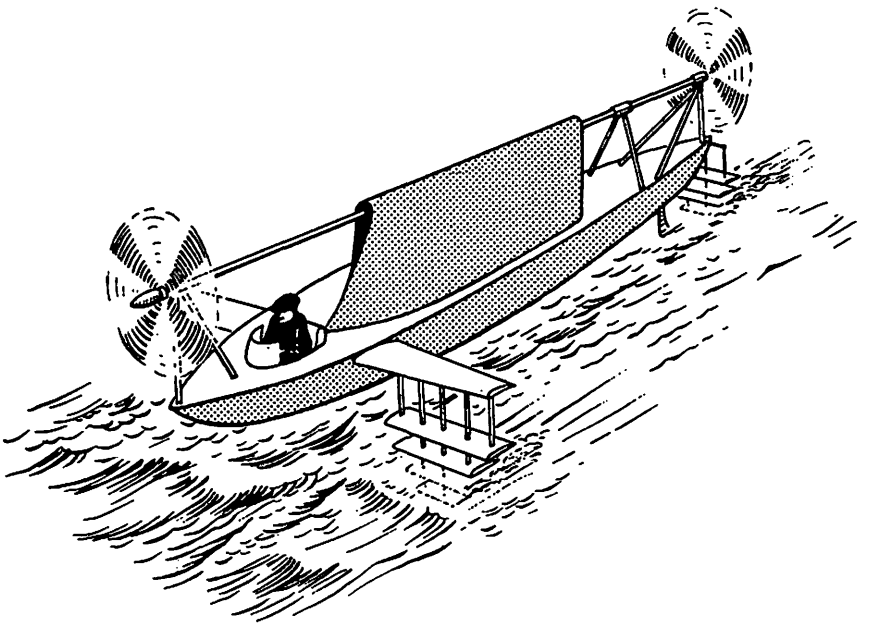


reduce water resistance—by means of wings, or foils, which lift the hull clear of the water and into the air.

The history of the hydrofoil, just like that of the aircushion idea, goes back a long way. In the middle of the last century, a French priest by the name of Ramus seems to have demonstrated the principle of dynamic lift for the first time, taking his cue from the kite. He built a half-scale model of a flat-bottomed boat with wings and had it towed along by a horse. It never rose from the surface of the water because the Reverend's h.p. was insufficient, and there were no other prime movers at that time apart from the heavy and cumbersome steam-engine. Ramus died, disappointed, before the early internal-combustion engines had been developed.

But his idea lived on and was taken up by another Frenchman, the Russian-born Count de Lambert, in the 1890's when small petrol-engines were already available. He called his prototype a 'hydroplane' and tried it out on the Seine, but it rose no more than the Reverend Ramus's craft had done. The Count, however, was not at all disappointed but switched his efforts to the development of the aeroplane, to which he contributed with his experiments.

Still, the hydrofoil idea was far from dead, but it was now another country, Italy, where it found adherents. An airship designer by the name of Enrico Forlanini, then in his late fifties built a small hydrofoil boat in 1905. The whole scientific and technical principle of the craft emerges very well from Forlanini's patent specification. There he states that a boat

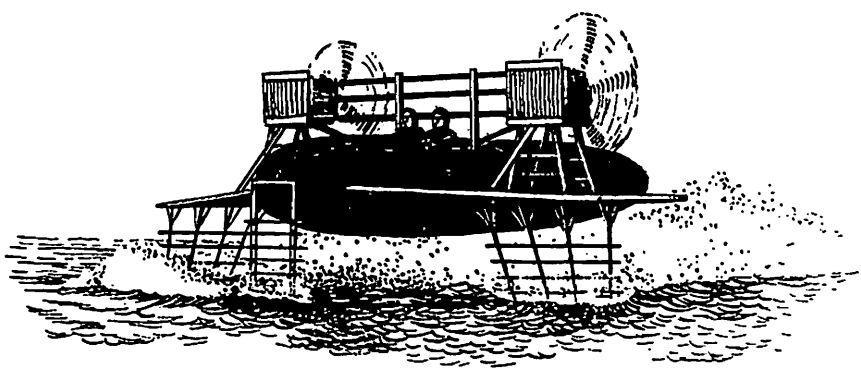


Enrico Forlanini's 'hydro-aeroplane' (1905), the forerunner of the modern hydrofoil

with, say, four small aircraft-type wings would show a lift increasing as the square of the speed; therefore, all four foils are needed to lift the craft out of the water, but then only one for cruising. 'Because of the proximity of the two media, air and water,' Forlanini continued, 'the elimination of the three unwanted foils is particularly easy. I merely have to stack them up, one above the other. Therefore, the resistance of my set of foils no longer increases as the square of the speed, but it is constant and independent of the speed. This is the first marine craft in the world with this advantage——'

So his first experimental craft was a small, one-man boat, with two airscrews, one fore and one aft, powered by a petrol-engine, and three sets of foils: one on each side towards the front of the boat, and one at the rudder. The hydro-aeroplane, as Forlanini called his invention, seems to have been moderately successful at its trials, but he went on to produce a number of other designs which were not. One of them had six wings high above the water; they could be folded back, like those of a modern swing-wing aircraft, to reduce air resistance once the front of the craft had lifted itself out of the water. In 1911, Forlanini's hydrofoils must have been something like a tourist attraction on Lake Maggiore, for he was visited there by no less a technical pioneer than Alexander Graham Bell, the inventor of the telephone. Forlanini invited Bell for a ride on the lake, and Bell acquired the licence to use the Italian's patents in the U.S.A. and Canada. He set up a research workshop at a lake near Halifax, Nova Scotia, and built a hydrofoil which set up a new world speed record on water—71 m.p.h. It was a torpedo-shaped craft with two aero-engines; it had step-ladder-type foils at the bow and stern and on each beam as well as short wings on which the craft rested when floating on the water.

Bell's hydrofoil, launched in 1918, skimmed very well on the water, and



The *Water Monster*, an early hydrofoil designed by Alexander Graham Bell, the inventor of the telephone. It established a water speed record of nearly 71 m.p.h. in 1918.

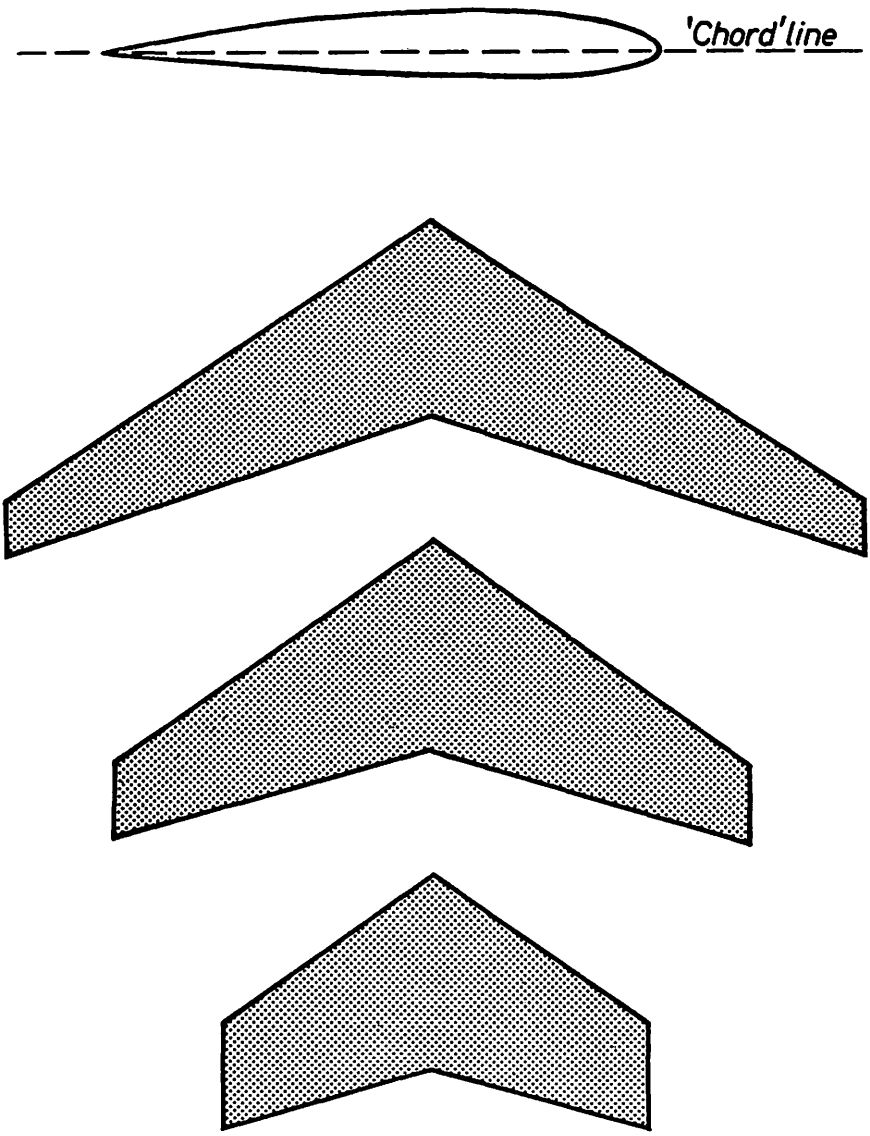
the mere fact of the speed it achieved shows that the Scots-born American inventor was working on the right lines. He offered the design to the U.S. Navy, but was turned down. However, his associate, Casey Baldwin, continued to work after Bell's death in 1922, and succeeded in selling two 'hydrodromes', as he called them, to the British Navy for tests off Spithead. Probably the tests were not carried out the way Baldwin intended (it is said that there were no powered runs but only tow tests behind naval craft in heavy seas); at any rate, interest in Britain subsided as well, and for a long time the hydrofoil idea seemed buried in Britain too.

Not, however, in Germany, where a number of engineers took it up in the 1920's and 30's. The one who really succeeded, though only after a lifetime of toil and struggle, was the aero-engineer Hans von Schertel. He received financial and technical help from a rich colleague, Gottard Sachsenberg, and technical support from an Italian firm of shipbuilders in Messina. Here, the first commercial hydrofoil boats, called 'Supramar', were built after the Second World War, based on the Schertel-Sachsenberg design. They were sold to a number of countries; many are still in use today. Details of the Supramar system are a commercial secret.

There was a curious incident during the 1939–45 war. The British captured a hydrofoil which Schertel had built for the German Navy, and took it to Portsmouth. The Americans wanted to know something about it, but the British Navy classified its booty as top secret and refused to part with any information. So the Americans began their own research programme—a quarter of a century after they had given Bell the brush-off. Now, however, they began to look around at the various designs that were being, or had been, developed in other countries, and in 1956 the U.S. Navy organized a competition for the most efficient one. It was won by the British 'Hydrofin', because it met all the requirements of a landing craft. But then the Americans tried to improve the basically simple British design with all kinds of sophisticated space-age devices—electronic control, sonar-beam sensing of oncoming waves and the like; this started a controversy which is still going on in many countries where hydrofoils are being designed and built.

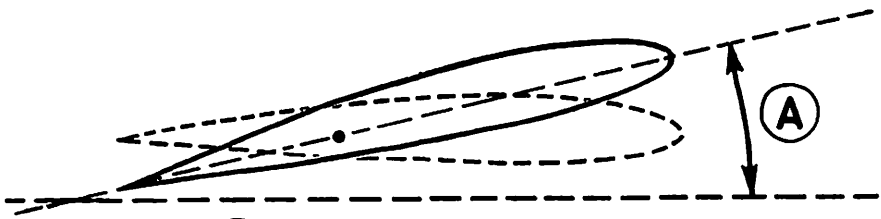
The story of the Hydrofin is quite dramatic. It is linked with that of Christopher Hook, a British organ-builder who had settled in the south of France with his French wife when the Germans occupied it in 1942. He escaped to Africa and began to work on the hydrofoil idea, which had interested him for a long time. With the help of some Italian prisoners-of-war and Kenyan labourers, using what aircraft scrap materials were available, he built in Mombasa 'a frightful looking but very instructive craft', as he described it himself. Further development had to wait until Hook was able to return to England after the war, where he designed the craft he called 'Hydrofin'.

With this system, the pilot can vary the angle of the foil, which in turn varies the height at which the hull travels over the water, and he can do it on either side separately when banking. Although Hook's early models



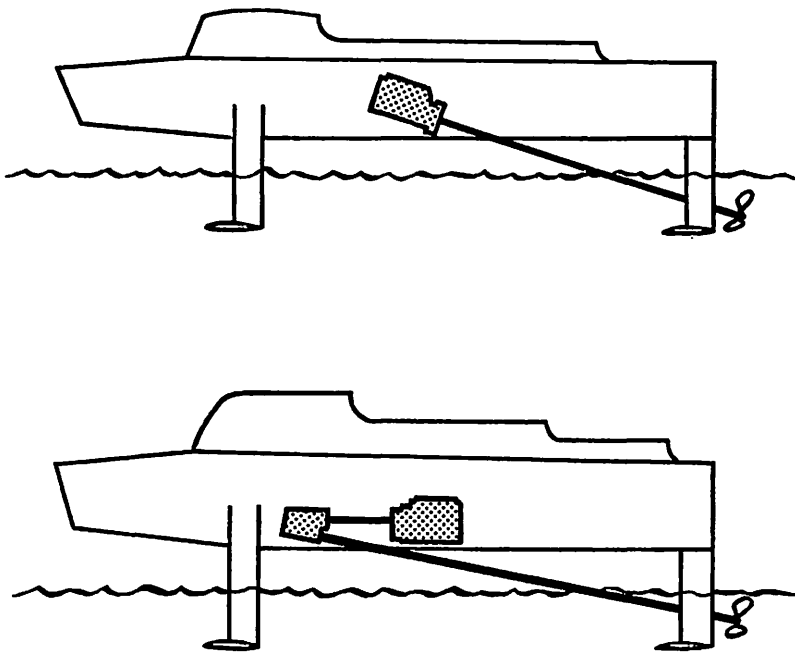
The surface design of a hydrofoil wing must be carefully worked out. Area, angle and ratio of foil to chord determine the performance of the craft

were driven by airscrews, the perfected Hydrofin uses the 'marine drive'—an ordinary water-screw on an extra long shaft reaching down from the stern, because this is the only part of the craft that *must* stay below the



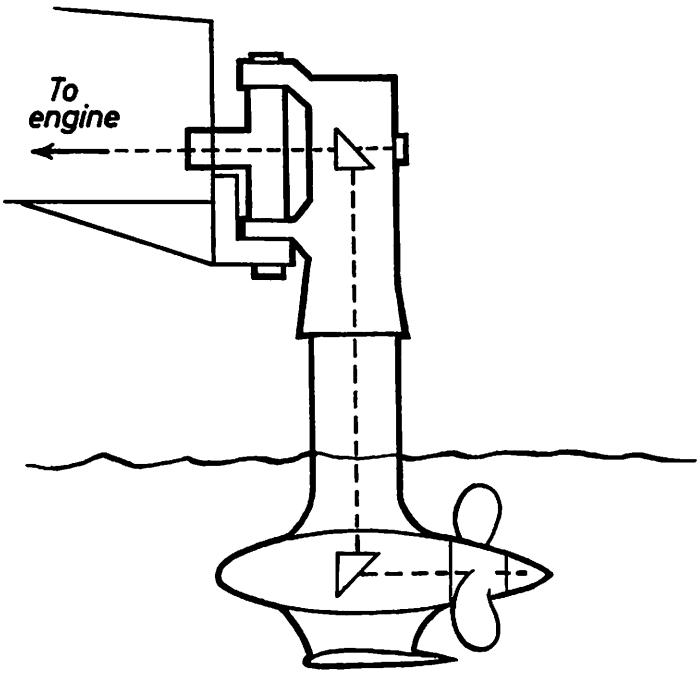
(A) *Angle of Incidence.*

The 'angle of incidence' of the foils can be varied according to requirements, either mechanically by the pilot or automatically by servo-mechanism

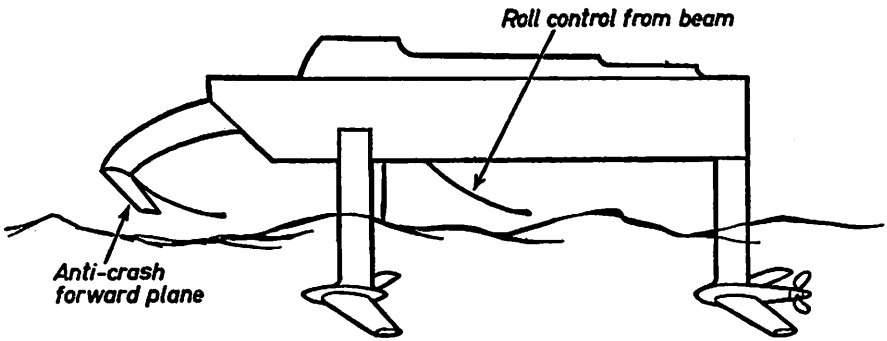


Two water-screw propulsion systems by inclined shaft

surface when the hull rises above the waves. Most hydrofoil types developed in other countries are using the marine drive today, though one occasionally finds propulsion by water-jet or airscrews.

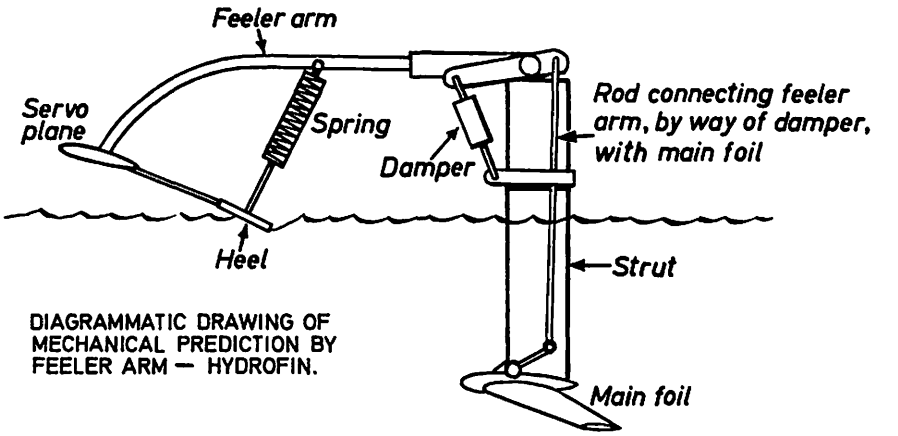


Water-screw propulsion by 'Z' drive



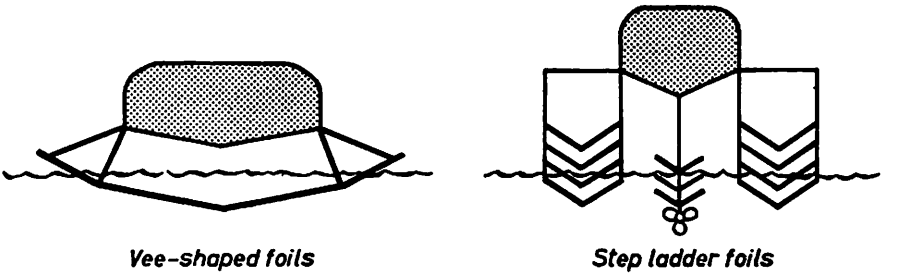
Christopher Hook's 'New Hydrofin' design. Oncoming waves are 'predicted' by the anti-crash forward plane, or servo-plane, which is normally above the water surface; roll control is effected from beam under the bottom of the craft

The Hydrofin system has one particularly interesting feature: it 'predicts' the waves which the craft is going to meet so that the pitch of the foils can be changed accordingly. This 'advanced wave prediction' is done by a small fin, or plane, reaching down into the water from the bow like an elephant's trunk. The three sets of foils—on both sides and on the screw-drive column below the stern—change their pitch by means of servo-mechanisms so as to meet the incoming waves at the most effective angle.

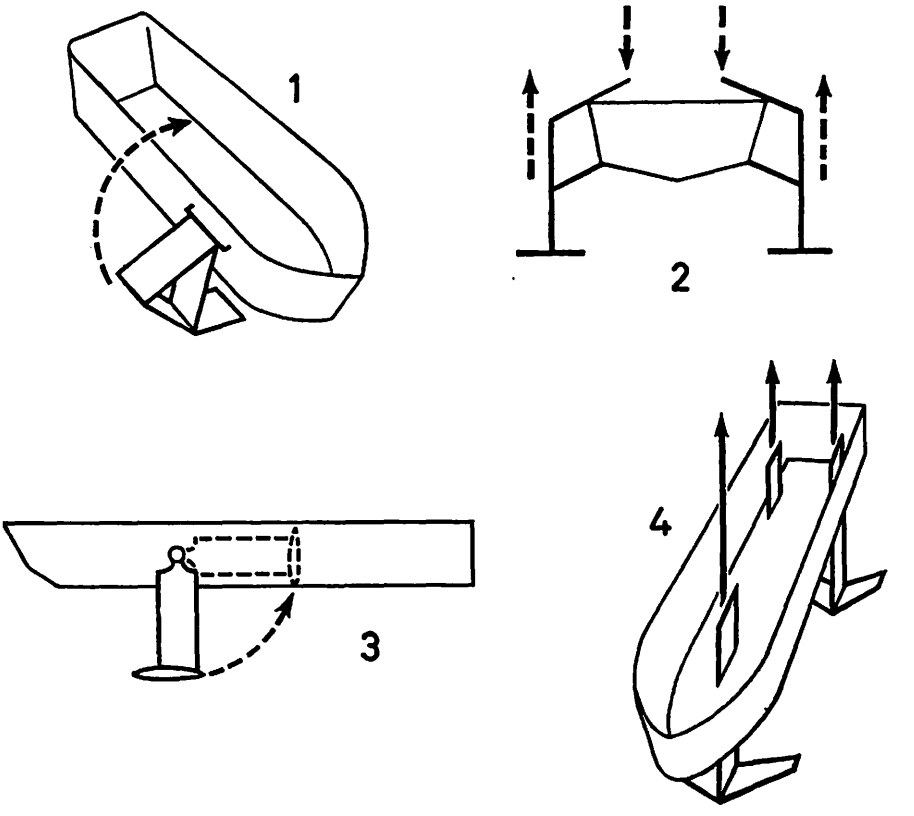


How the 'wave prediction' system of the Hydrofin works, altering the foil angle of incidence according to wave conditions

Nearly all the hydrofoil types in use today have a rather clumsy look—like giant insects on bowlegs. This lack of elegance is due to the arrangement of the foils which has been found most practical: in V-form, which means that the struts holding the foils stick out from the hull right and left. The V-foils of the Supramar and the Hydrofin form a continuous plane below the bottom of the craft. The Russian hydrofoils designed for



The two main designs in foil arrangement for lift and stabilization. Modern hydrofoils mainly use the Vee shape



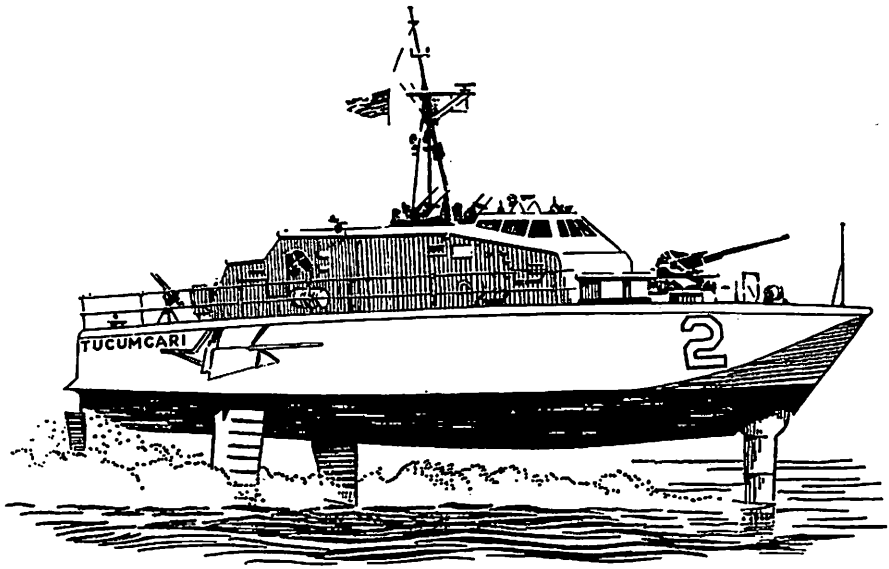
Four systems of controlling the foils by retracting or extending them according to requirements

smooth inland waterways, however, look somewhat more elegant because their foils are fixed vertically on the hull, without long struts; but they cannot rise very high from the water. Here, the emphasis is on high speed and large carrying capacity.

There is no doubt that the hydrofoil is a serious challenge to the hovercraft on short-distance routes, but the picture of development in the various countries that are building them changes continuously. The hydrofoil designers aim at producing larger and larger craft, if possible ocean-going. The Supramar boats, now being manufactured on the shores of Lake Lucerne in Switzerland and under licence in Italy, Norway, Japan and other countries, seem to represent the most advanced design. Although construction details are not available, we know that the biggest type, carrying 250 passengers or 150 passengers plus eight cars, has a cruising speed of 39 knots (72 km/h.) and a range of 300 miles. Powered

by two German 3,400 h.p. diesel engines, it can negotiate waves of up to 12 feet height without undue discomfort to the passengers.

In America, the Boeing aircraft company is building military hydrofoils for the U.S. Navy as personnel and weapon carriers and submarine chasers. Half a dozen other designs have been developed for commercial

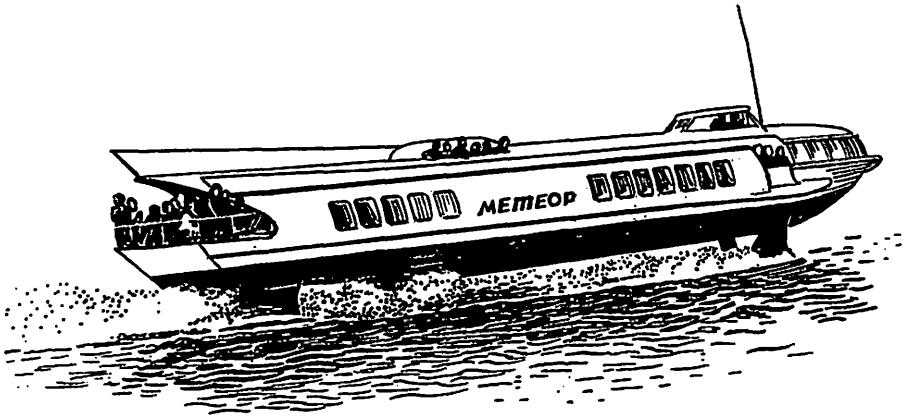


The *Tucumcari*, launched in 1969, the U.S. Navy's first hydrofoil gunboat. Propelled by water-jet engines, it reaches 45 m.p.h.

transport and as sports boats, by shipbuilders and aircraft corporations such as Grumman of Bethpage, N.Y. Canada has built her own naval hydrofoil, a 150-feet submarine chaser designed to reach speeds up to 60 knots in 20-foot waves, and capable of remaining at sea for two weeks at a time. The cost, however, is quite formidable—50 million dollars.

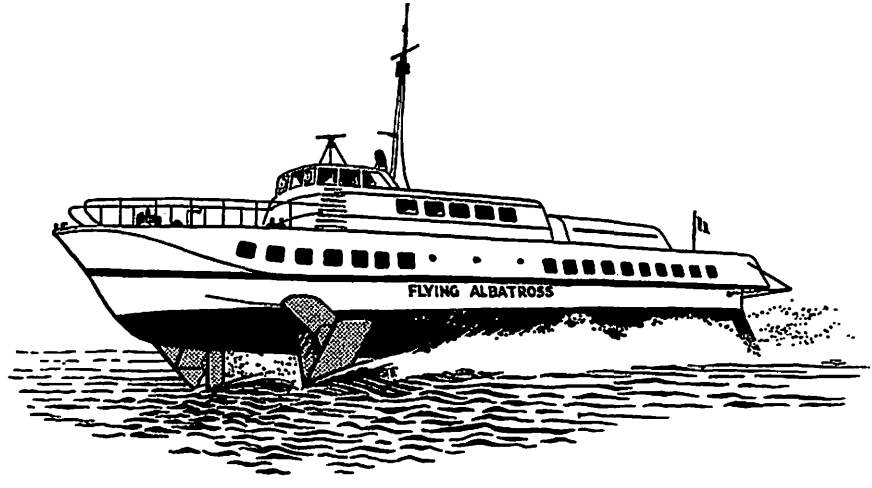
The Soviet Union, traditionally reticent about its technical projects, must have built quite a number of hydrofoils for military purposes, but what we know for certain is that hundreds of passenger-carrying craft are in daily operation on the rivers and lakes of the country. One, probably the largest type, has been operating in the Black Sea since 1962; it can carry 300 passengers and is said to behave well in rough weather. Its cruising speed is 50 knots, its range 500 miles. Somewhat smaller is the 'Burevestnik' type, designed for rather shallow water; it is propelled by two water-jets, and is said to have a cruising speed of 70 knots but cannot negotiate waves of more than 4 feet.

Apart from those two countries, Russia and America, which both like to try out and develop new technical ideas, the hydrofoil is now in



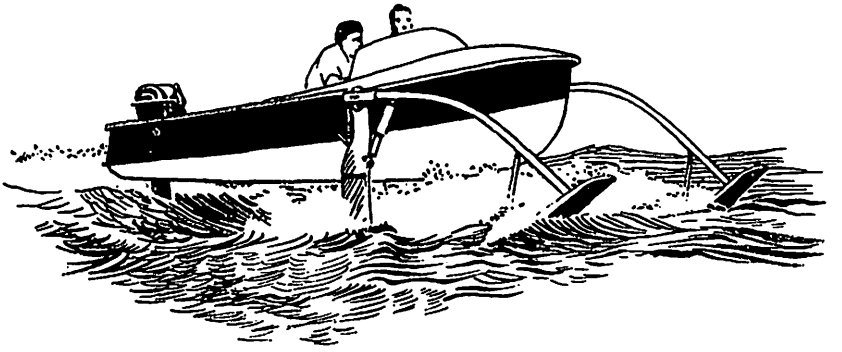
The *Meteor*, a Russian river-service hydrofoil for 150 passengers

constant use in Japan, Scandinavia, Holland, Australia, New Zealand, Yugoslavia, Egypt, Greece and South America; hydrofoil ferries operate across the Straits of Messina and between the Channel Islands and St Malo in France, providing fast and reliable service. Their running costs seem to be low enough for successful competition with conventional ships, and they are hardly affected by weather conditions. Where Forlanini tried out his first craft, on Lake Maggiore between Switzerland and Italy, a hydrofoil boat carries passengers from one end to the other in less than half the time needed by the old-style motorboats.

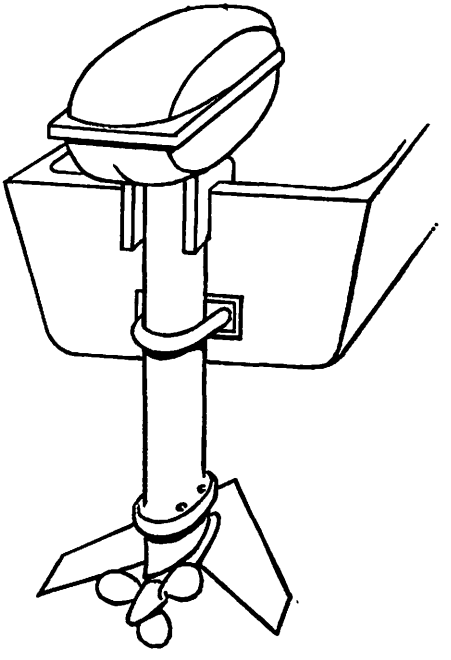


The *Flying Albatross*, a Supramar hydrofoil built in Italy. Two of these boats maintain a regular ferry service across the Straits of Messina.

The enormous variety of purposes for which the hydrofoil is suitable, in preference to other ships, has now been recognized. It makes a splendid fast craft for fishery patrol and protection. It carries crews to and from oil-drilling platforms off the coast—highly-paid men who must get to their place of work as fast as possible because their time is valuable. Hydrofoils are being used as pilot boats, in air/sea rescue operations, for firefighting. They have been found particularly suitable as harbour customs launches and river police boats—they can follow some suspicious ship at a slow pace with retracted foils, then extend them for full-speed flight and overtake the ship for investigation. The hydrofoil is faster than anything afloat, with the exception of a few types of speedboat.

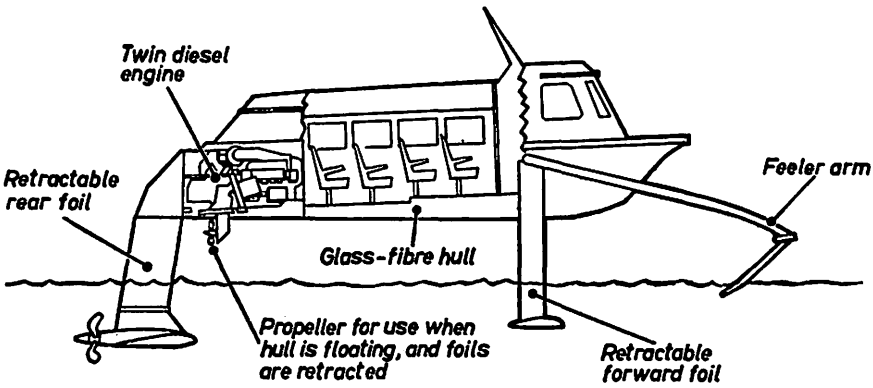


Speedboats can be converted into hydrofoils at comparative low cost—but you have to be an accomplished do-it-yourselfer



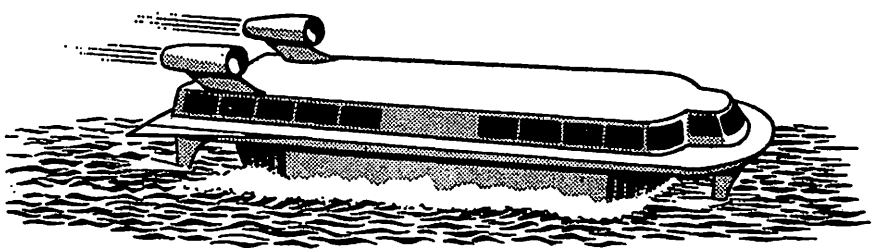
A conventional outboard motor can be fitted with a hydrofoil fin

London's first hydrofoil commuter service, with an Italian craft built in Messina, Sicily, was opened in May 1972, conveying passengers between Tower Pier and Greenwich in 10–15 minutes (normally a 25-minute trip). The service, said the leader of the Greater London Council in his inauguration speech, may restore the river 'to its age-old function as one of the capital's main highways'.



Britain's *Sea Ranger* (1969) has a range of 200 miles and cruises at *c.* 40 knots. It has a 'wave-prediction' forward plane and can travel in shallow water with retracted foils and underwater propeller, using a second small propeller directly under the hull

We are bound to encounter hydrofoils in increasing numbers in all countries where passengers and goods have to be moved on inland waterways, and we may very well see them as ocean-going craft in the near future. We may even be able to travel on board a most curious hybrid of a boat—a hovercraft equipped with hydrofoils. American engineers have been studying the possibility of building this craft, which would ride on its aircushion at slower speeds, but rise with the help of its foils and stub wings much higher than other hovercraft; it could be propelled by air-screws or turbo-jets. There is no telling where the re-thinking process in transport engineering, which we are now witnessing, may lead.



A hybrid vehicle—hovercraft with hydrofoils

FURTHER READING

Hovercraft by John Vass ('Now' Books, Macdonald & Co Ltd, London 1969)

Hydrofoils, by Christopher Hook and A. C. Kermode ('Without Formulae Series', Sir Isaac Pitman & Sons Ltd, London 1967)

Hovering Craft & Hydrofoil, International Review (Kalerghi Publications, London)

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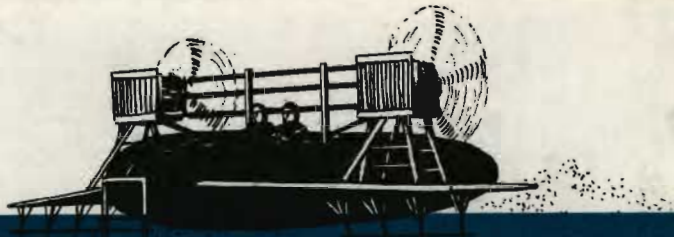


TUCUMCARI
2


FLYING ALBATROSS