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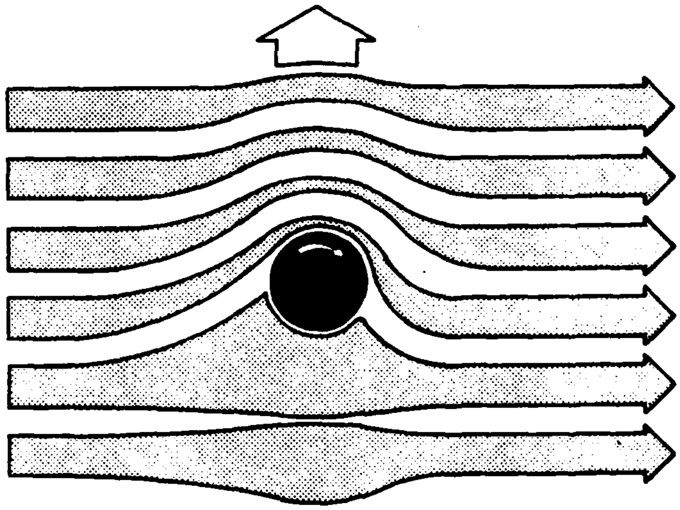
MAGNUS EFFECT

—

AN OVERVIEW OF ITS PAST AND FUTURE PRACTICAL APPLICATIONS



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NAVAL SEA SYSTEMS COMMAND
DEPARTMENT OF THE NAVY
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The report is in two volumes and is intended to present the known data and past and future applications of Magnus effect devices. (Magnus effect devices are very high lift devices which can be used in applications where airfoils are currently used.)

The first volume includes the history of Magnus effect devices, theory and principles, a significant patent review, practical marine applications, formulas and experimental data, comparisons of Magnus effect and other state-of-the-art devices, identification of further testing needed, and a proposed test program. Appendices include rudder research and a literature critique. Keywords: Flettner rotors;

The second volume is a collection of the drawings for 39 Magnus effect patents plus a critique of each patent evaluating its potential, especially for marine applications.

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"THE MAGNUS EFFECT - AN OVERVIEW OF ITS PAST AND FUTURE PRACTICAL APPLICATIONS"

VOLUME I

PREPARED BY THE BORG/LUTHER GROUP
FOR
NAVAL SEA SYSTEMS COMMAND
DEPARTMENT OF THE NAVY
WASHINGTON, DC 20362

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CONTENTS - VOLUME I

FORWARD

The material in this technical report has grown out of extensive research performed the the Borg/Luther organization. We wish to acknowledge fully the efforts of Borg & Luther whose creative energy went into providing this theoretical, practical, and utilitarian information which can be used throughout marine-related projects.

In 1853, Gustav Magnus recognized a phenomenon which has encouraged later scientists to invent solutions to similar problems beyond that provided by his discovery. This technical report consists of a collection of Magnus effect principles, techniques, and specialized theories that meet the needs of the novice, experienced engineer and naval architect.

The report is presented in two volumes and is intended to serve as a comprehensive reference source and study guide for academic and industrial groups on the various aspects of the Magnus effect.

Volume I provides extensive discussions of the historical, theorectical, and practical aspects of the Magnus effect. It also presents research data and establishes criteria for further development and testing.

Volume II comprises a collection of authoritative documentation relevant to Magnus effect techniques including patent descriptions and accompanying illustrations.

SYMBOLS AND ABBREVIATIONS

A = area
A/R = aspect ratio
b = breadth or length of spar
C = coefficient
c = constant
C_D = coefficient of drag
C_L = coefficient of lift
D = drag force, parallel to direction of flow (resistance)
d = diameter (of rotor)
de = diameter of end plate
F = force
ft = feet (12 inches or 30.48 centimeters)
g = acceleration due to gravity
hp = horsepower (550 ft. lbs./second)
L = lift force, perpendicular to direction of flow
l = length
lbs = pounds (16 ounces or 0.4536 kilograms)
M = moment
M_H = heeling moment
r = radius (or effective radius)
R_N = Reynold's number
rpm = revolutions per minute
S = surface area
T = torque (generally expressed as pound feet)
V = velocity of flow
v = velocity of surface
α (alpha) = velocity ratio (V/v)
Γ (gamma) = circulation
π (pi) = ratio of circumference to diameter
ρ (rho) = mass density (expressed in slugs/cubic foot)

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CHAPTER 1

INTRODUCTION

This study has been prepared with the intent of providing a broad overview of the past and future practical applications of the Magnus effect. The employment of this phenomenon as a means of increasing the efficiency of watercraft is emphasized throughout because marine use most readily lends itself to improvement by this means. Included in the report are its historical as well as its technical aspects and both successful and unsuccessful machines and methods are discussed. A large bibliography and an extensive collection of patents regarding the subject are also to be found in the text, to assist those interested in future design research.

The "Magnus effect" is the peculiar lifting force manifested upon a rotating body when subjected to a fluid flow or current which impinges upon that body and is perpendicular to its rotational axis. This lift is quite similar to that of the familiar inclined plane type of supporting surfaces such as wings, propeller blades, rudders etc. The principal differences are that the Magnus effect lift can be many times greater in magnitude, given the same projected area and flow velocity than wing lift and furthermore it cannot stall.

The phenomenon is named for Professor Gustav Magnus, who first defined it in a paper written in 1852 (Ref. 1). His experimental work established that a lifting force is develcped by a spinning cylinder placed in an air flow.

The Magnus force behaves much like the electromotive force which causes deflection or "lift" in an armature when a wire conductor is positioned between the poles of a magnet. The magnetic field can be likened to the air flow of the Magnus experiment in that it has a direction or polarity.

The field encirling the electrified wire resembles the boundary layer of air upon the surface of the rotating cylinder. The rotor and the conductor both behave in the same fashion and are deflected in a direction that is perpendicular to the path of the wind or of the field between the magnetic poles.

The Magnus effect is easily observable in nature and is most obvious in the movement of weather systems. A familiar example occurs in the Gulf of Mexico each summer with terrifying regularity.

A hurricane will stall over open water and build up wind velocity in a counterclockwise direction (as viewed from above). It continues to drift very slowly westward until it encounters another moving air mass. If the wind is from a northerly direction, the storm, influenced by the Magnus effect, will move rapidly westward and will come ashore somewhere between Brownsville, Texas and the Yucatan Peninsula. If, on the other hand, the wind originates from a more easterly direction, the hurricane becomes a threat to Biloxi, New Orleans or some other Gulf Coast city; the Magnus lift propelling the rapidly rotating air mass northward.

When it became possible, through experimentation, to predict the magnitude of Magnus effect forces in terms of surface and flow velocities, the door was opened for inventors to explore its many useful possibilities. The applications now include rotary sails, rudders, propeller blades, wings, wind turbines in numerous configurations, ship stabilizers, and even a heavy lift airship supported by a rotating gas envelope. Often Magnus effect devices have proven to be superior in some way to the state-of-the-art equipment presently performing the same function.

Magnus effect systems promise to increase operational capabilites and to decrease operating expense, thus yielding higher performance per dollar. Simplicity and compactness are the main reasons. Rotating cylinders are mechanically simple, inexpensive to construct, fuel efficient, and manpower cost effective.

Designing a Magnus effect device today is not significantly more difficult then it was in the 1920's when the first rotor sail propelled ships made their debut. Today's engineers can call upon computers to analyze structures, control experiments and test and tabulate data. This may permit them to translate more quickly from design to final completion, thereby accelerating the second chance for this long neglected concept to serve the marine industry.

CHAPTER 2

HISTORY AND BACKGROUND

The story of the Magnus Effect began in the year 1671 when the first record of the drift deviation of a spinning body was described by G. T. Walker. The body was a "sliced" tennis ball.

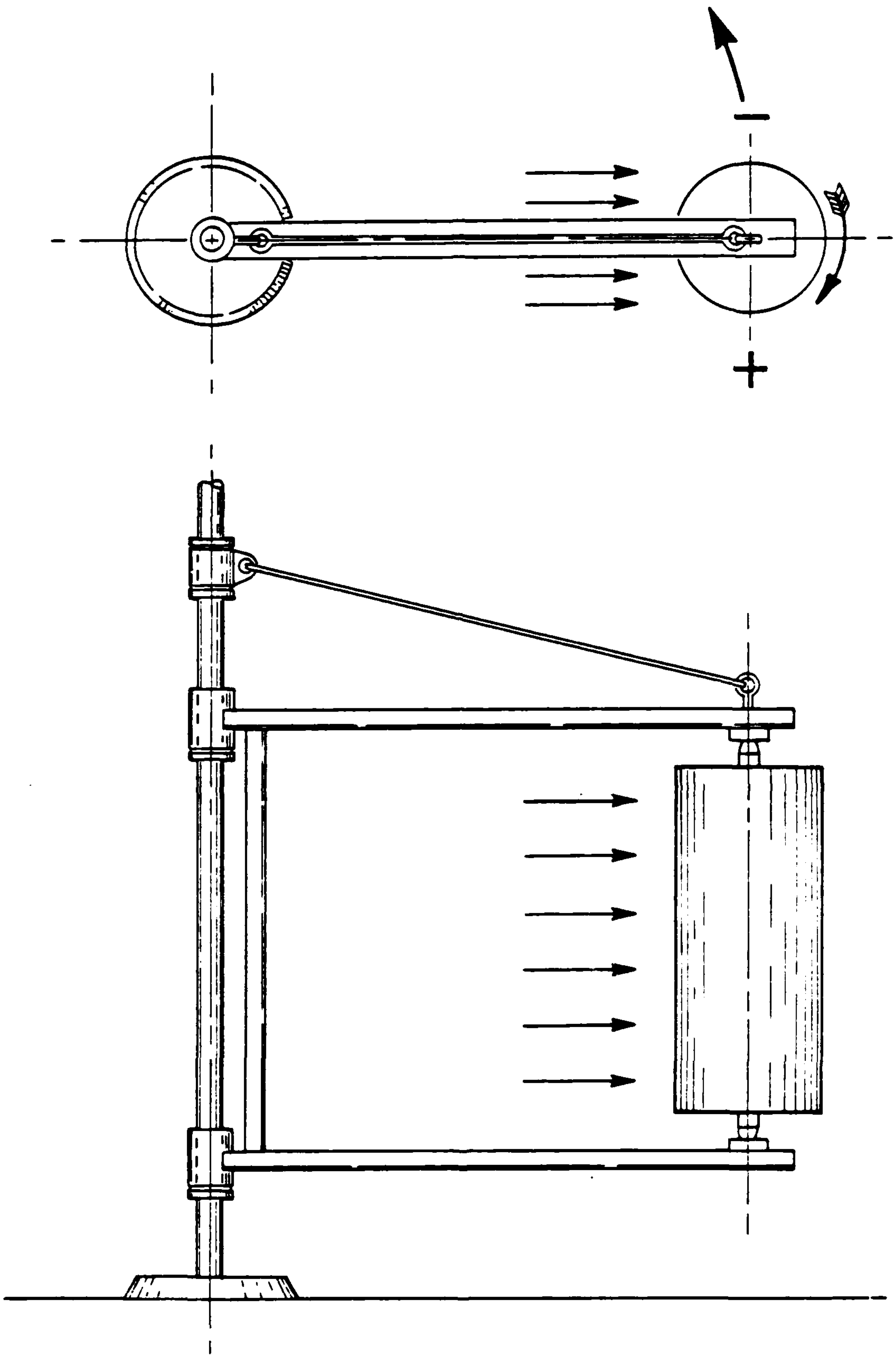
In 1794 the Berlin Academy offered a prize for the solution of the problem of unpredictable deflection of artillery projectiles. The eminent physicist Gustav Magnus supplied the answer in an expose' entitled "About the Deflection of Projectiles and a Peculiar Phenomenon Noticed in Rotating Bodies" published in 1853 (Ref. 1).

Gustav Magnus was Professor of Physics at the University of Berlin during the years 1834 to 1869. Hermann Ludwig Ferdinand von Helmholtz, famous for his mathematical elaboration of the conservation of energy, was one of his pupils. Professor Magnus was also an instructor at the Artillery Academy. His well known experiment was conducted in 1852. It consisted of a brass cylinder held between two conical bearings to which he could impart a high speed of rotation by means of a string, in the fashion of a boy spinning a top (Figure 1). He mounted the cylinder upon a freely rotatable arm and directed a current of air from a blower towards it. When the cylinder was revolved he noticed a strong lateral deviation. The spinning body always tended to deflect toward the side of the rotor that was traveling in the same direction as the wind coming from the blower. Immediately Magnus recognized that he was dealing with the same phenomenon causing the mysterious deflection of projectiles. The magnitude of the deflecting forces was not measured by Magnus at that time.

As for the effect upon the artillery, it resulted from a rapidly spinning round emerging from a rifle-grooved gun barrel and encountering a strong cross-wind. If the projectile was rotating in a clockwise direction, as viewed from the rear, and the wind was blowing from the left, a lifting force would develop and it would impact somewhere beyond the target. If the wind chanced to be blowing from the opposite direction on the same projectile the lift would be negative or downwards and it then would fall short of the mark.

In the year 1877 Lord Rayleigh wrote a treatise "On the irregular flight of tennis balls" (Ref. 2). It appeared in the "Messenger of Mathematics" and attempted to explain the curved path of a ball in terms of the Magnus effect.

The first marine use of the Magnus effect was reported by Captain La Croix (Ref. 3). He mentioned that a missionary in Shanghai, China around 1895, fitted a sampan with a single rotor, activated by hand operated gears. The sampan then moved faster



GUSTAV MAGNUS' EXPERIMENTAL APPARATUS

FIGURE 1

than rowboats of comparable size.

It was not until 1912 that appreciable headway was made in the investigation. In the "Revue de Mechanique", Professor Lafay published an article entitled "Contribution experimentale à l'aerodynamique du cylindre et à l'etude du phenomene de Magnus" (Ref. 4 & 5). In this report he tells about experiments which he had conducted in the Physical Laboratory of the Ecole Polytechnique and in the Etablissement d'aviation militaire de Vincennes. His thorough tests demonstrated that by using rotating cylinders, even those without end plates, one may attain several times the output in lift of a plane surface having the same projected area.

The work of Lafay materially contributed towards clearing up the ideas on the origin and mode of action of the forces of the Magnus effect. His measurements showed how pressure and suction are distributed around the cylinder and how the streamlines are deflected. Lafay's report remained almost unknown in Germany but even in France and other countries where it received more publicity, it did not lead immediately to any inventions.

About this same time Professor Ludwig Prandtl also investigated rotating cylinders (Ref. 6). His purpose was not to measure forces but rather to examine the flow conditions for two cylinders rotating in opposite directions. A single cylinder was also studied but Prantl states that not much value was attached to these experiments.

In 1918 Professor Foettinger wrote an article in which he discussed experiments relating to the lateral forces acting upon rotating cylinders placed in a current. He concluded that as far as current forces are concerned the rotor functions similarly to an inclined plane.

In 1919, acting upon a suggestion made by Foettinger, Professor Guembel constructed a propeller having rotatable cylindrical blades. It worked but the two scientists decided that the device had no practical value (Ref. 7).

Although a number of Magnus effect propeller concepts have been patented during the years following the successful Foettinger and Guembel experiment, none has yet been put to practical use, but in theory, at least, rotary bladed propellers are capable of producing considerably more thrust per horsepower than the conventional type.

Soon after the propeller experiments, the true prophet of the Magnus effect appeared upon the scene. His name was Anton Flettner and he was one of the most imaginative and versatile engineers of this century (Ref. 8 & 9). Some of his early inventions included a radio controlled horse and a robot military tank. His first major contribution was the trim tab actuated balanced rudder. These were originally used on large flying boats and soon afterward on ships. The "Flettner Rudder Company" was organized to produce and market this new steering system.

In 1922 Anton Flettner collaborated in organizing the Institute for Hydro and Aero Dynamics located in Amsterdam. His project here was to design an auxiliary sailing ship using metal sails resembling airplane wings.

While he was aware of the promising results of contemporary Magnus effect experimentation, the idea of using the phenomenon to propel ships was not immediately apparent. Flettner's inspiration came to him while vacationing at a resort in Tavemuende. The inventor was enjoying a carefree afternoon, drinking tea, listening to an orchestra play and engaging in trivial conversation when he suddenly had a very vivid vision of a great sailing ship with a huge revolving white tower.

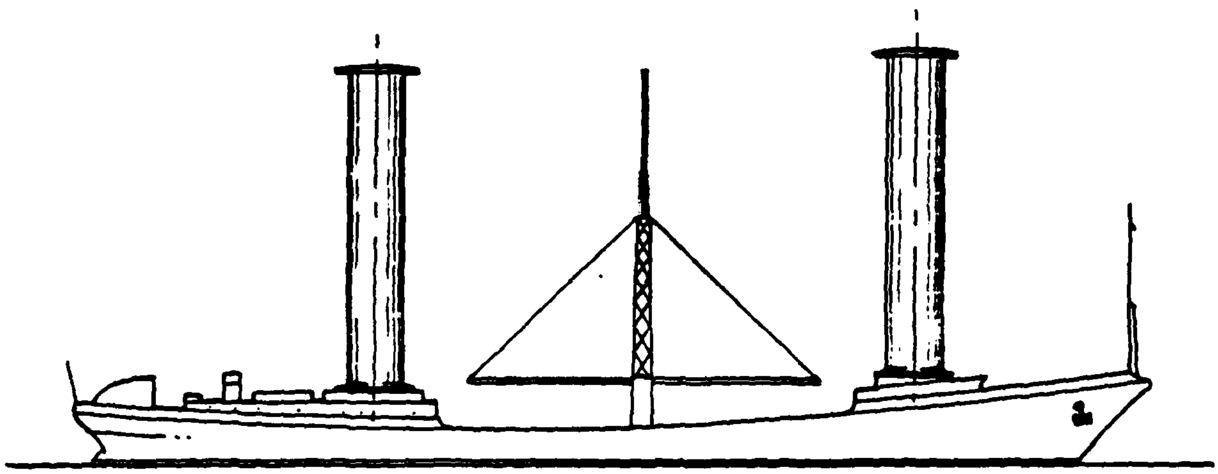
This revelation came to him after he had spent the morning on the beach explaining the Magnus effect to his wife. As a demonstration, he built a small mound of sand and started some particles rolling down from the top. Then, inserting a fist into the flowing sand he executed a slow rotary movement of 180 degrees. On the side of the hand moving with the flow, the grains were hurried along while on the opposite side they were brought to a standstill.

Soon after the inspirational vision at Tavemuende, Flettner constructed a crude model boat fitted with a cylindrical cardboard sail spun by a clockwork mechanism. The little tin boat was launched at a lake frequently used by model sailboat builders where it sailed smartly across the water to the astonishment of the observing hobbyists. Now convinced of the advantages of rotor sail propulsion he was prompted to discontinue the work with wing type sails and concentrate on his latest brainchild.

Upon completing verification tests at the experimental station, a patent was applied for that encompassed a large variety of Magnus effect sail configurations and rotor blade windmills. From the experiments it was concluded that a rotor could produce 8 to 10 times the driving force of conventional sails having the same projected area, and was 4 to 5 times more efficient than the wing sails being studied.

Anton Flettner was now faced with the problem of convincing his client, Friedrick Krupp A. G. Germaniawerft, who had already accepted the idea of airplane wing type sails, to switch to rotor sails. He managed this by performing wind tunnel tests on a scale model of the retrofit vessel, a three masted barkentine, the "Buckau", later renamed the "Baden-Baden" (Figure 2).

The topside weight reduction more than doubled the stability of the Buckau even though the rotors' skin was made of 3/64 inch thick steel plate and they were mounted upon 5 feet in diameter by 43 feet tall unstayed steel pivots.



ROTORSHIP "BADEN-BADEN"

LENGTH	164'-0"
BEAM	39'-0"
DRAFT	13'0"
MAIN PROPULSION	200 HP SINGLE SCREW
ORIGINAL SAIL AREA	8500 SQ FT
ROTOR SAIL AREA	850 SQ FT
ROTORS (2 EACH)	
DIAMETER	9'-2"
HEIGHT	51'-2"
AUXILIARY GENERATOR	40 HP
ROTOR DRIVE MOTORS (2 EACH, REVERSIBLE, 3:1 REDUCTION GEAR)	11 KILOWATTS 220 VOLTS 750 RPM

FIGURE 2

There was much concern about how the ship would ride in a storm. The rotors could not be reefed like ordinary sails and technology did not yet have the capability of producing a gigantic telescoping or inflatable cylinder. Tests indicated, however, that when the rotors were turning at maximum speed the wind force acting upon them virtually ceased to increase. At that time such behavior was explained by the absence of a suction-causing eddy on the lee side of the rotating cylinder.

During the sea trials of the "Buckau" it was learned that she could be sailed much closer to the wind than was possible with the conventional sail plan. It was also possible to steer the vessel by changing the rotational speed of the rotor sails and even to sail in reverse.

In 1926 the ship, now named the "Baden-Baden," arrived in New York, having traveled a distance of 6,200 nautical miles and sailed up the Hudson River at a smart 8-1/2 knots under rotor power. She had crossed the Atlantic by way of the Azores encountering terrific storms in the Bay of Biscay and off Cape Hatteras. The rotor sails actually proved to enhance the safety of the ship since they served to retain steering control while the wheel and rudder were useless during a running sea.

The ship returned to Europe, where a bolt of lightening damaged one of her rotors. Since the planned test runs had been completed, the ship was sold. Later, once more fitted with conventional sails, the Baden-Baden was lost in a *hurricane*. In all probability the ship would have survived if the rotors had been left on (Ref, 10).

With this remarkable voyage Anton Flettner became world famous and was besieged with all kinds of outlandish Magnus effect schemes, most of them useless. One concept of a very practical nature did emerge from all of this. It was proposed by Commander Sigurd Savonius of Finland and was acquired by Flettner's company as a subsidiary patent.

The now well-known Savonius rotor consists of a pair of semi-circular sections as though a circle was split and the two halves shifted to form a sort of broken letter "S" (Figure 11). It is an autorotor that exhibits the Magnus effect to a certain degree. Its peripheral speed is not sufficiently greater than the flow velocity to be used to propel a ship, except in very high winds. It did prove to be a practical, inexpensive, omnidirectional wind turbine, however. It's odd that the Savonius rotor has found greater public acceptance than Flettner's rotor sail. It is now sometimes crudely constructed from halves of a 55 gallon steel drum mounted on an axle.

The Savonius autorotor and its more efficient latter day descendents may still have a strong future as wind energy converters.

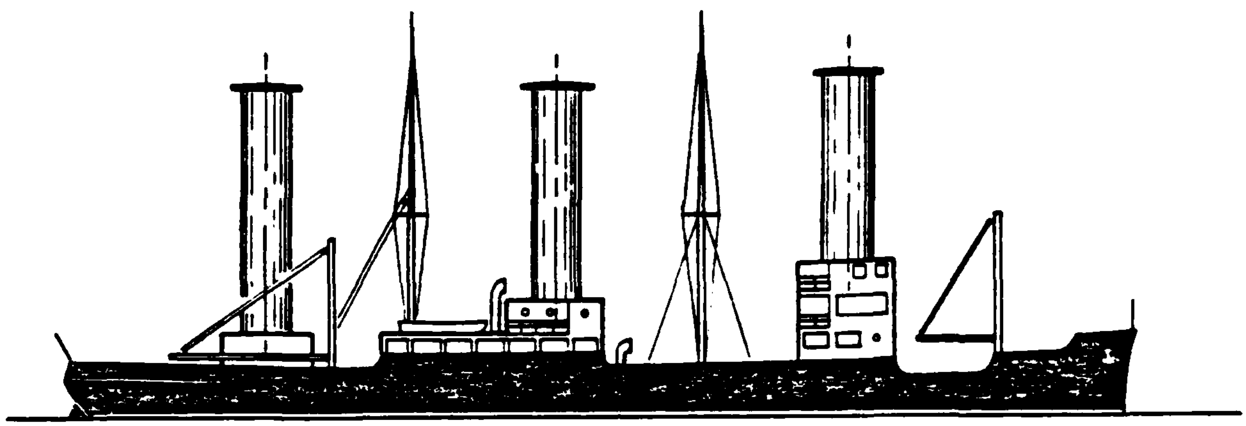
The European landscape never became dotted with Magnus effect windmills. Nor, for that matter, did the seas become crowded with rotor powered ships. One can only conjecture about the decline in interest in this attractive form of energy conversion. Perhaps the worldwide financial depression of the 1930's that saw seaworthy ships rusting away at their moorings for lack of cargo, caused the Flettner rotor idea to go into hibernation. It is also possible that the abundance of cheap fossil fuels killed the rotor ship project right along with the majority of other commercial sailing vessels of the world.

After 1930, little was heard of Anton Flettner and his Magnus effect revolution until he emerged in the aftermath of World War II. He had been involved in the design of a German combat helicopter. The project was completed too late to be used in the conflict but his talents were recognized by the Americans and in 1945 he became a consultant for the United States Navy. His last major project was the founding of his own helicopter manufacturing company in the United States. Anton Flettner died in 1961.

Shortly after the success of the Baden-Baden became known to the world, a Mr. Julius D. Madarasz of Royal Oak, Michigan developed yet another way to use Flettner rotors to produce electrical energy. His invention is discussed in detail in Chapter 4 of this study. The Madarasz machine consisted of a series of trolleys coupled together on a circular track, each having a large electrically driven rotor and generator. This scheme was a practical way to extract large amounts of power from the wind. A single rotor unit was constructed and demonstrated but it failed to attract enough investment capital to carry out the complete project.

The Magnus effect seems to have gone underground during the entire mid-third of the Twentieth Century. Its only sign of life was in the area of toys, mainly kites. It wasn't until 1979 that the Van Dusen Commercial Development Company of Canada designed what may be the first working Magnus effect flight system. It is a revolving spherical gas balloon with a "U" shaped fuselage suspended beneath it. Motors at the upper tips of the "U" drive the sphere's axle. Thrusters at the same location furnish forward motion and directional control. A scale model of the aircraft, 65 feet in diameter, has been tested and the company intends to promote the device as a low speed, high lift cargo carrier.

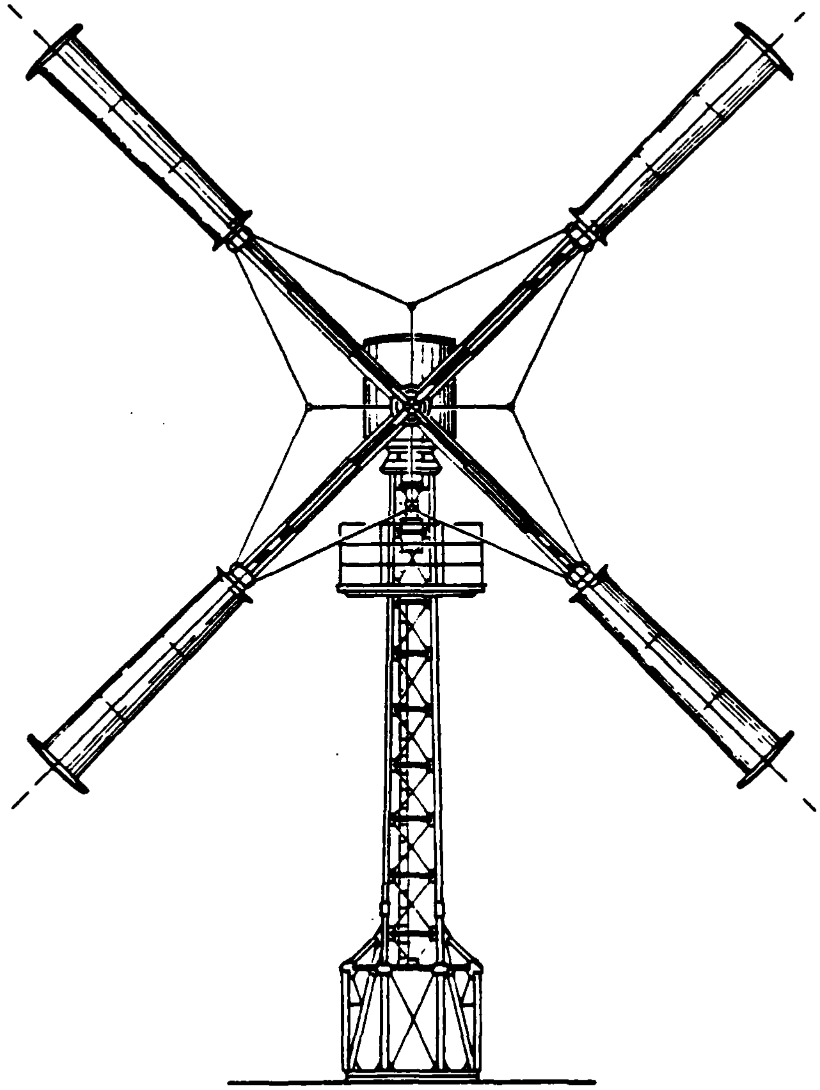
The latter part of the 1970's saw a revival of interest in Magnus effect steering systems for ships. Three West German vessels, (Ref. 11), and at least one Soviet ice breaker, (Ref. 12), have been outfitted with rotary rudders. In 1980 the twin screw towboat "Escatawpa" was fitted with a pair of Magnus effect rudders and in 1982 a tuna seine skiff with a single cylindrical rudder was tested. A detailed review of the performance of these two vessels is given in Appendix A of this study.



ROTORSHIP "BARBARA"

LENGTH	300'-0"
BEAM	43'-0"
DEPTH	
(KEEL TO POOP DECK)	27'-0"
CARGO CAPACITY	3000 TONS
MAIN PROPULSION	2 DIESEL, SINGLE SCREW
	1060 HP
ROTORSAILS (3 EACH)	
DIAMETER	13'-2"
HEIGHT	56'-1"
ROTOR SPEED	150 RPM
ROTOR DRIVE (3EACH)	35 HP ELECTRIC MOTORS

FIGURE 3



ANTON FLETTNER'S WINDWHEEL GENERATOR

FIGURE 4

A renaissance in Magnus effect sailing vessels is presently occuring. On June 9, 1983, the renowned underwater explorer Captain Jacques Yves Cousteau announced the successful sea trials of the "Moulin à Vent", (the "Windmill"), (Ref. 13). This vessel is a catamaran 65 feet in length and is a test platform for a unique cylindrical sail. While superficially resembling a Flettner rotor, Cousteau's new wind propulsion system is a 13.5 meter high elliptical tube with a fan incorporated at the top. Wind is sucked into the sail through one of a pair of longitudinal slots or vents that are facing downwind. The boundary layer is moved by suction rather than by surface friction as with a rotor sail. This has the effect of deflecting the air current thus propelling the vessel. The cylinder can be oriented and the slots closed on either side to generate lift from the wind moving past the sail.

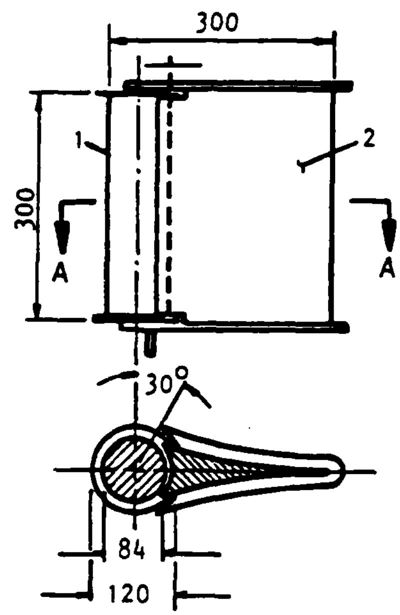
The project was financed by the French Ministries of Industry and the Sea and by the French Energy Agency. It was led by Professor Lucien Malavard of the French Academy of Sciences.

The Moulin à Vent lost her "sail" during an Atlantic crossing in December of 1983. In spite of the accident, Captain Cousteau is satisfied that the propulsion system performed successfully. The demise of the mast did not reflect a weakness in the concept, only the inadequacy of the platform and the method by which it was attached (Ref. 14). Cousteau intends to outfit the new 260 foot "Calypso II" with a pair of the vented cylindrical sails.

The Soviet publication "Sudostroyeniye" carried a discussion entitled "Marine Aerodynamic Propulsive Device with Enhanced Efficiency" (Ref. 15). The system consists of a Flettner rotor positioned at the leading edge of a wing. The intent of the arrangement is to improve the downwind performance of the rotor sail and to reduce drag when the vessel is going to windward under engine power only (see Appendix C). A model was tested in a wind tunnel and a twin rotor version of the system has been developed (Figure 5). In this configuration the two units are mounted on horizontal yards and carried on a single, central support column. A fabric, roller reefed square sail can be suspended between them.

The dual rotor-wing wind propulsion arrangement was applied in theory to a tanker of the "Altay" class. Two assemblies were called for having rotors 2 meters in diameter and 10 meters long. In order to obtain the same amount of thrust, 6 isolated Flettner rotors would be required.

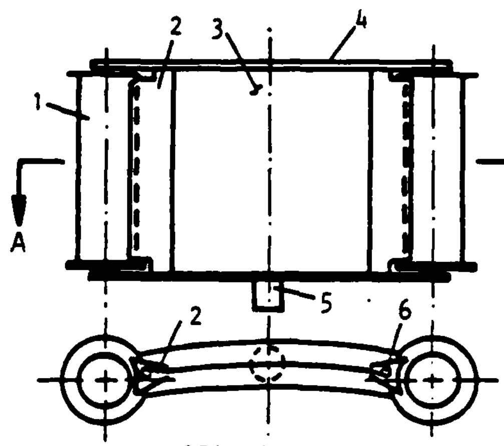
The proceedings of the Thirteenth AIAA Symposium on the Aero/Hydronautics of Sailing (Ref. 16) contains a report entitled "Magnus Rotor Test and Evaluation for Auxiliary Propulsion". The work was done by L. Bergeson and C.K. Greenwald of Wind Ship Company, Norwell, Massachusetts and T.F. Hanson of Windfree, Inc., Newhall California. Hanson's work was also featured in "Popular Science" magazine (Ref. 17) in an article on his Magnus effect air turbine system (see Chapter 4).



SOVIET WIND TUNNEL TEST MODEL

1 - ROTOR; 2 - WING

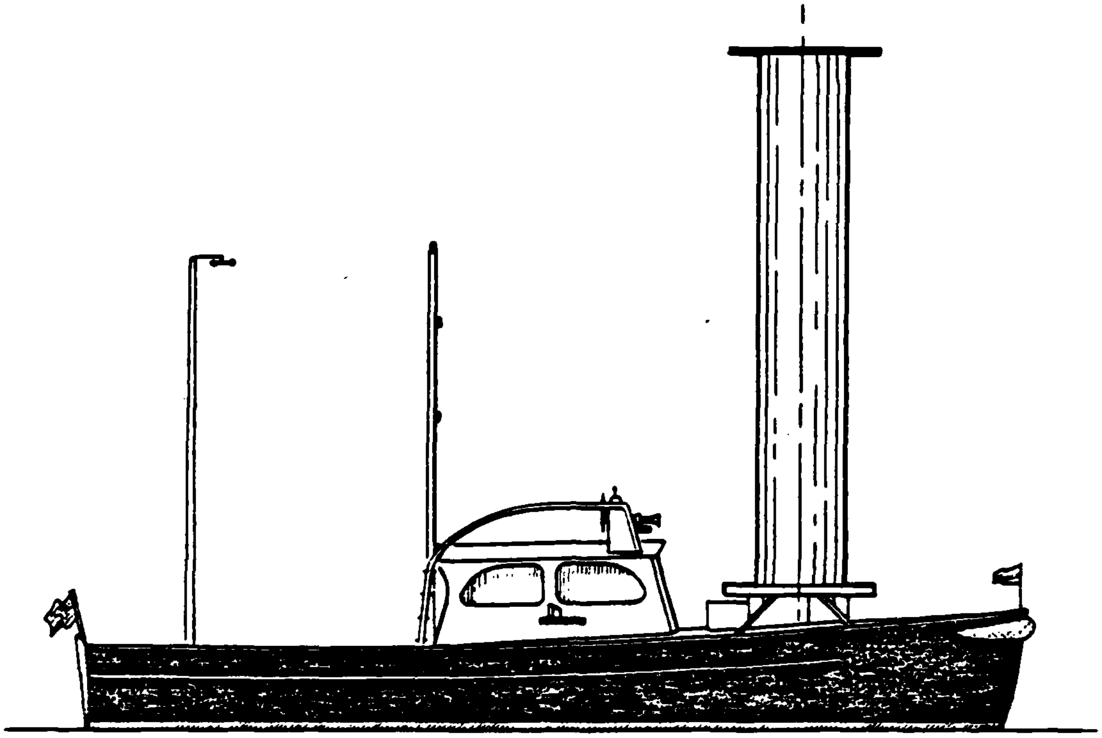
(NOTE: DIMENSIONS IN MILLIMETERS)



TWIN ROTOR SYSTEM

1 - ROTORS; 2 - ROTOR FAIRINGS; 3 - SAILS; 4 - YARDS; 5 - SUPPORT COLUMN OF PROPULSIVE DEVICE; 6 - SPINDLES FOR WINDING THE SAILS

FIGURE 5



ROTOR YACHT "TRACKER"

LENGTH	42'-0"
DISPLACEMENT	18 TONS
ROTOR	
DIAMETER	3'-9"
HEIGHT	23'-9"
ROTOR SPEED	600 RPM(MAX)

FIGURE 6

A Hanson windmill rotor was installed, instrumented and tested aboard the 18 ton, 42 foot motor vessel "Tracker" (Ref. 18). The results confirmed Flettner's projects and the potential of the rotor sail as a reliable and economically viable sail-assist device for fishing vessels and commercial ships (Figure 6). Performance of the Tracker is good with speeds in excess of 8 knots with the engine off. The coefficient of lift of the rotor sail approached a value of 13 at a speed ratio of 5, well in excess of Flettner's lower aspect ratio rotors.

Further rotor sail experimentation has recently been conducted by two Swedish Naval Architects, Ake Williams and Hans Liljenberg and is described in a paper presented at the SNAME Annual Meeting in November, 1983 (Ref. 19). A 6 meter test boat was fitted with a collapsable rotor made of sail canvas. Performance was better than expected proving that, from an aerodynamic point of view, fabric can be used for the rotor shell.

Based upon experience gained on the 6 meter boat, Williams and Liljenberg have designed rotor sail propulsion systems for a 12 meter fishing boat and 950 dwt coaster named the "Stellan."

It seems that the Flettner rotor sail has once again caught the fancy of naval architects and may now be considered a leading contender among sail assisted propulsion systems. Other marine applications of the Magnus effect, such as propellers, stabilizers and rudders, have not yet attracted as much interest. Climbing operating costs have stimulated a search for increased efficiency, so it is safe to assume that a significant amount of development will soon take place in these areas.

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CHAPTER 3

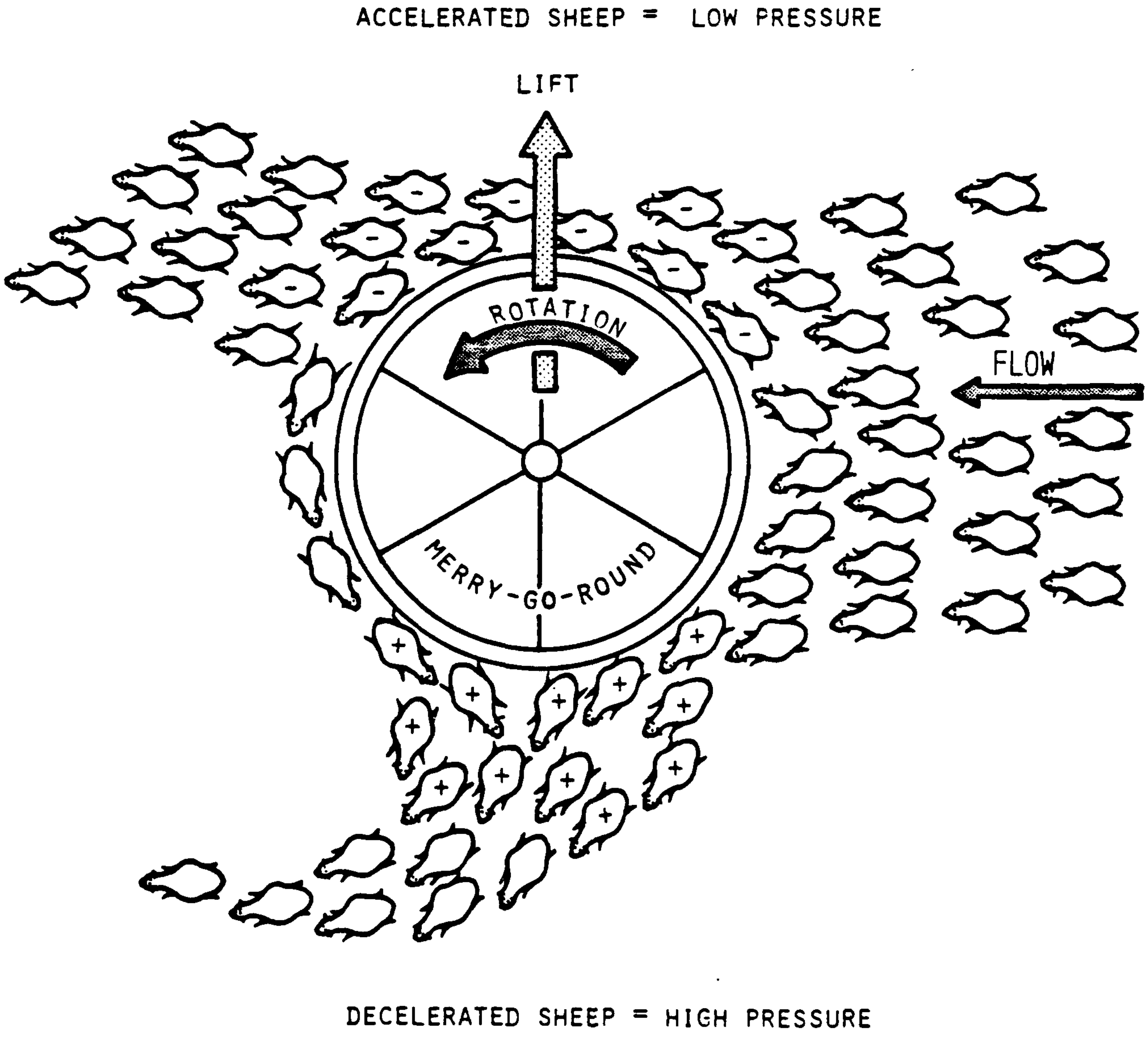
PRINCIPLES OF THE MAGNUS EFFECT

Anyone who has observed a baseball game or a tennis match has seen the Magnus effect in action. The spin imposed on the stitched leather ball by the pitcher causes it to travel in a curved flight path, thus hopefully confusing the batter. It's doubtful that many ball players have a definition for the phenomenon, they are simply aware that by gripping the ball in a certain way and throwing it in a fashion known only to themselves, what looks like a "ball" to the batter passes over home plate and becomes a "strike". A tennis ball will perform similarly when "sliced" so as to have spin. If the ball is struck in such a way that its top is moving opposite to the direction of flight, it will have more "lift". As the backspin diminishes, it will assume a normal trajectory causing difficulties for the player who is attempting to return the ball (Ref. 20, 21 & 22).

Like behavior is exhibited by any rotating body, such as a cylinder, in a flowing fluid. As the rate of spin increases, so does the lifting tendency. A spinning cylinder will perform in exactly the same way in a gas or in a liquid but the magnitude of the lifting force increases with an increase in the mass-density of the fluid.

The fluid medium surrounding a spinning rotor may be visualized as concentric circles resembling a section of a sliced onion. The boundary layer nearest the core circulates most rapidly and the speed diminishes with each subsequent ring. As the fluid begins to flow past the cylinder, these concentric layers arrange themselves into streamlines and as the rotational speed increases those on the side moving in the same direction as the flow converge, indicating diminished pressure. The streamlines on the opposite side, moving against the current, become more widely spaced showing an increase in pressure. This pressure differential manifests itself as a "lifting" force and tends to displace the rotor at a right angle to the fluid flow and in the direction of the side of the rotor that is moving in the same direction as the fluid stream (Ref. 23).

The Magnus effect can be illustrated with the idea of a moving flock of sheep (Figure 7), representing a two dimensional model of a flowing fluid, upon encountering a merry-go-round. As the mass of animals moves past the revolving carrousel those adjacent to the side turning in the same direction they are moving tend



A FLOCK OF SHEEP ENCOUNTERS A CARROUSEL DEMONSTRATING
THE MAGNUS EFFECT

FIGURE 7

to be accelerated. Those on the opposite side are slowed down, balk and mill about. Meanwhile the boundary layer of accelerated sheep fails to break away, is entrained and taken completely around the back of the wheel where they collide with the others that are halted. This combined group represents pressure and is deflected away at about 90 degrees to the direction of travel of the main herd at a much diminished pace.

Sheep probably wouldn't have much effect on a merry-go-round, but what if we substitute them with a herd of stampeding buffalo? In so doing the mass density and flow velocity of the medium would be greatly increased. In this case the carrousel would most likely be displaced or "lifted" in the direction of the faster moving portion of the herd.

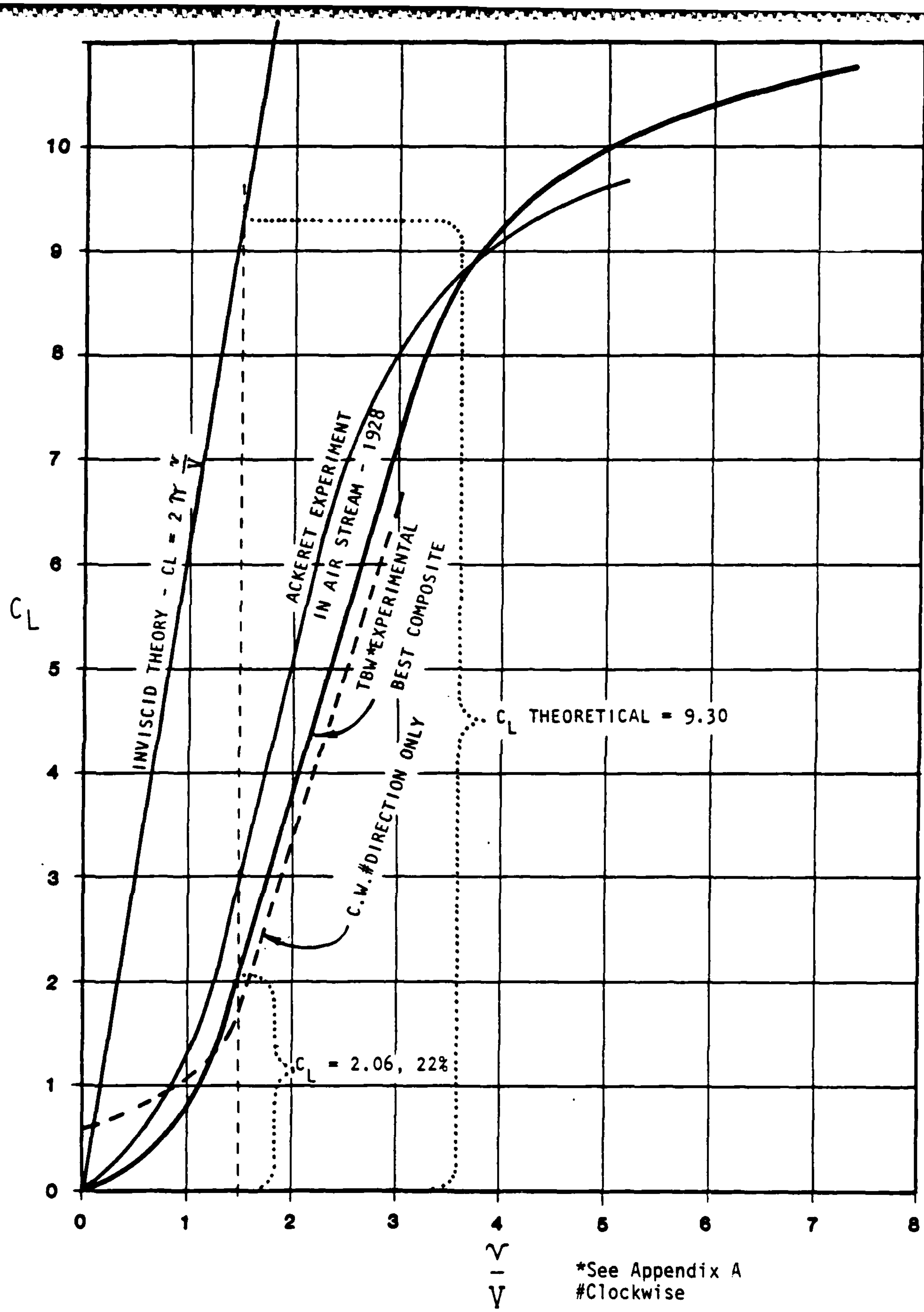
Due to the limited velocities of livestock and carnival equipment and to avoid trouble with animal protection groups, we'll return to discussing a three dimensional fluid such as air.

As one might expect, when the surface velocity of the cylinder becomes equal to the flow velocity the coefficient of lift is approximately one. As the velocity ratio increases, stagnation points on the cylinder move closer together until they meet when the surface velocity reaches twice the speed of the free stream. At this point, for rotors of proportions similar to Flettner's sails, the coefficient of lift jumps to a value between 4 and 5 (Figure 8). It increases to about 10 when the rotational velocity is 4 times greater than the flow.

Prandtl predicted that the limit of increasing lift would occur at a coefficient of lift of 4π, that is, above a surface speed of 4 times the free stream speed, no more vorticity would be shed into the fluid. Later experimenters have measured much higher coefficients. W.M. Swanson, (Ref. 24 & 25), whose paper is described in Appendix C of this report, mentions the possibility that greater lift values could be caused by the stagnation point rotating forward thus deflecting the wake further than was formerly presumed. A. Thom (Ref. 26) reported lift coefficients as high as 18 for cylinders with large aspect ratios and end plates of 3 times the rotor diameter.

In many instances a revolving cylinder can be used in place of an airfoil shaped wing or blade and with greater efficiency. As a substitute for a conventional sail or rudder, it is the compactness of a Magnus effect unit that makes it attractive. Flettner's sails had about one-ninth the area of the old rig they replaced. A rotor can change its lift by varying its rpm rather than changing its angle of attack, furthermore the rotor cannot stall!

A conventional ship's rudder, for instance, cannot be put hard over to more than about 35 degrees because at that point it enters a stall, ceases to function as a steering device and becomes a brake. This undesirable condition is eliminated by substituting a cylindrical Magnus effect rudder (Ref. 27). Similarly, propellers



*See Appendix A
#Clockwise

MAGNUS C_L AIR & WATER
FIGURE 8

with rotary "blades" would not exhibit what is known as "slip" because slip is a function of blade "pitch" or angle of attack, a condition not necessary for Magnus effect lift.

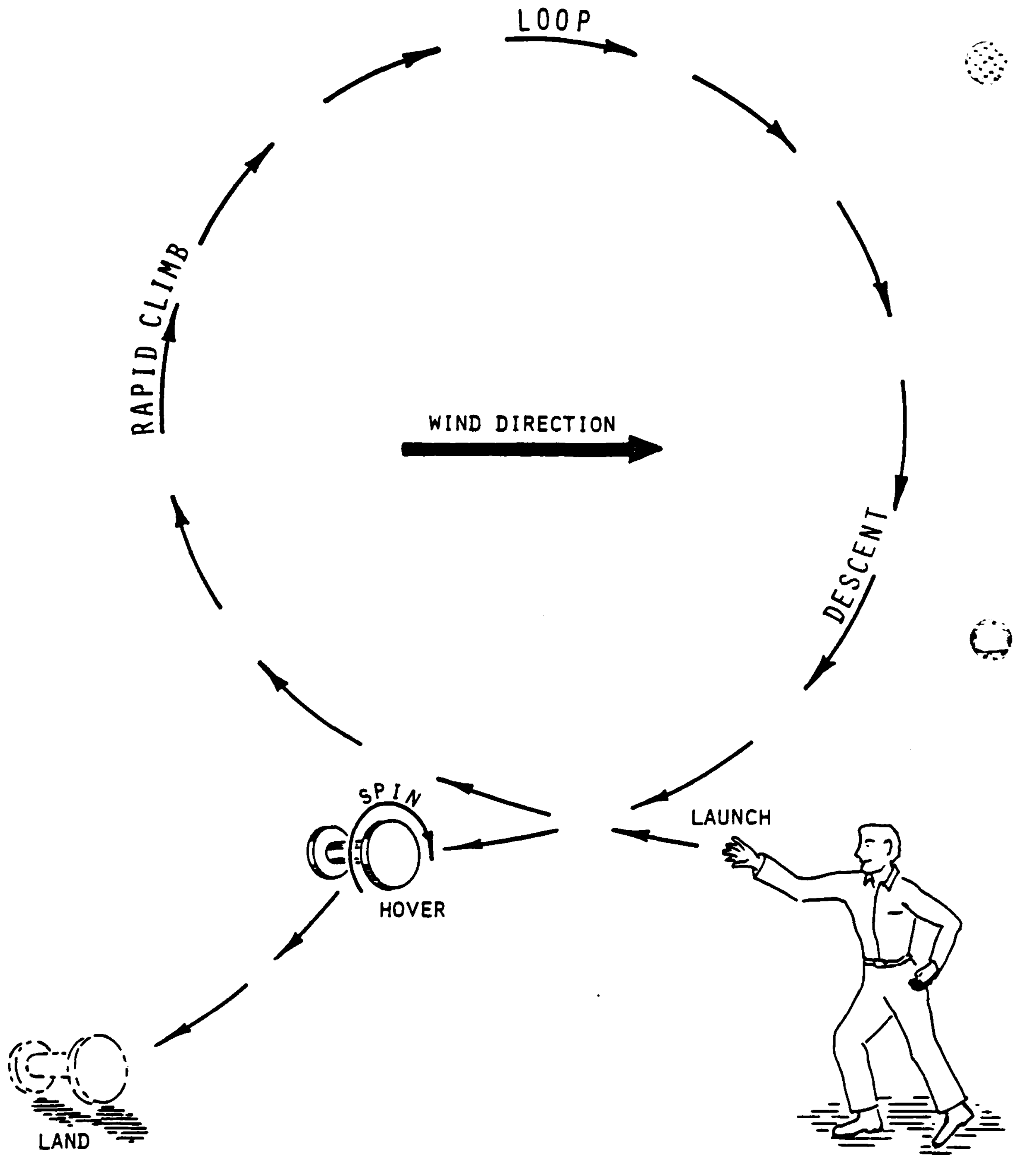
In addition to its inability to stall, a Magnus effect rotor possesses another useful characteristic, its ability to become "invisible" or at least tend to fade away under certain conditions. The "Barkley Phenomenon" was named for the gentleman who pointed out the characteristic to the author during model basin tests of rotary rudders. It had been noted by earlier investigators, but lacked an identifying name. It manifests itself as a distinct drop in drag acting against the rotor just prior to reaching a surface-to-flow velocity ratio of one. This means that the resistance of the cylinder tends to disappear at that point in a way not yet fully explained. One suggestion is that the eddy normally located behind a static cylinder is displaced to the pressure side and becomes part of the lift component.

Flettner made use of the Barkley phenomenon in hurricane conditions. His rotor sails had a maximum surface velocity of about 80 miles per hour so that in winds of 20 miles per hour they would have a surface to flow velocity ratio of 4 and an ideal lift coefficient of more than 9. When he encountered winds in excess of 80 miles per hour the velocity ratio dropped to less than one and consequently the wind resistance diminished dramatically. The stability of the ship was actually greater than a full rigged vessel under bare poles.

A similar circumstance was noted by T.F. Hanson (see Chapters 2 & 4). While testing his Magnus effect wind turbine, his wind velocity instrument recorded gusts of more than 80 miles per hour, yet the turbine rotor came through unscathed. Thus a Flettner rotor can be tuned to high wind speeds so as to be hurricane proof, an advantage not inherent in other type of lifting devices.

An interesting demonstration of the Barkley phenomenon can be conducted with a toy Magnus effect glider called a "Rotorang" (Figure 9). A light cylinder such as a paper towel tube is fitted with cardboard end plates and wrapped with a short piece of string so as to impart backspin when hand launched into a light breeze. The Rotorang will climb rapidly upwind to its maximum altitude then drift downwind and earthward, executing a perfect loop. It will continue to fly until its speed of rotation becomes equal to the wind at which time its resistance disappears. The glider will then hover several feet above the ground for an astonishingly long period. As the spin decays further the Rotorang will again assume a shallow glide path and will land some distance away.

A potential application for the Barkley phenomenon would obviously be for Magnus effect ship steering systems. A vessel with twin rotary rudders could maintain a course with the two cylinders counter-rotating at a peripheral speed slightly less than the



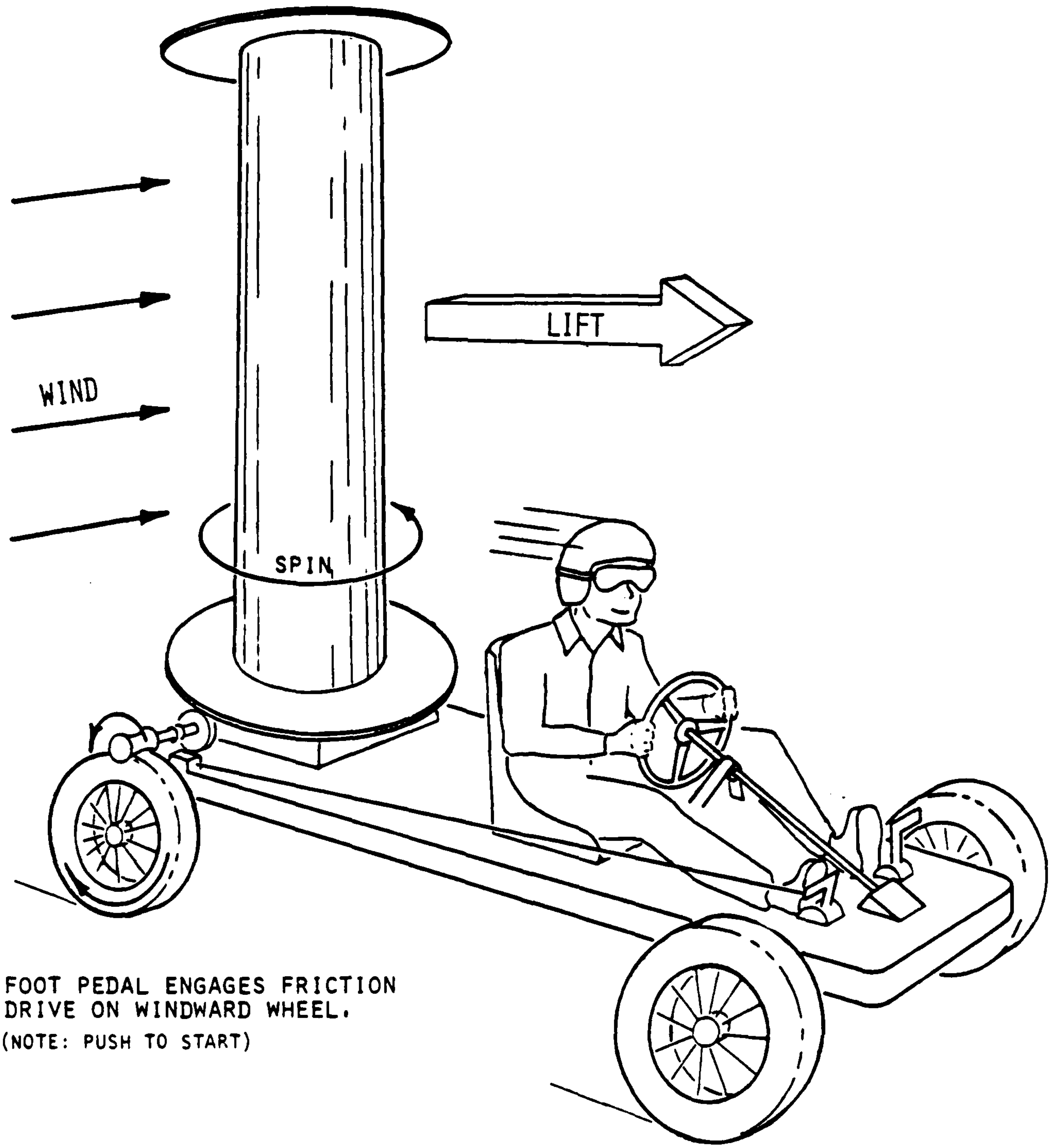
THE FLIGHT PATH OF A "ROTORANG"
FIGURE 9

wake velocity produced by the propellers. In this mode the drag will diminish to a fraction of that developed by a fixed cylinder or rudder. If the rotation of both rotors is inboard when viewed from above, they will act as a nozzle, directing the wake straight aft thus enhancing propulsive efficiency. For small corrections in heading the rotor on the side in which the turn is to be made would be speeded up somewhat to accomplish the maneuver. For more drastic changes in direction both rotors would be rotated in the same wise for maximum turning force. This steering arrangement would doubtless result in noticeable fuel savings since the power needed to spin rotors at low surface speeds is minute compared to propulsive horsepower wasted by the drag of a static rudder.

The selection of a means for imparting spin to a Magnus effect rotor depends upon its intended service. For example, a wind turbine may best be driven by mechanical means because it turns in one direction only, while a steering system rotor is constantly changing velocity and direction calling for a hydraulic transmission. Rotor sails, on the other hand, will probably not need to be reversed as frequently, so an electric motor with appropriate reduction gears would be most efficient. All of this is just another way of saying that the choice is up to the designer. There are, however, several other arrangements that should be kept in mind. The first is the belt driven by a flowing lubricant (G.G. Hirs, see Chapter 4). Bear in mind that the lubricating fluid may be air or even sea water. The second method is shown by G.D. Boehler (see Chapter 4) whereby spin is generated in the rotor by means of small jets or rocket reaction motors located in the end plates and operating pinwheel-wise.

Because the Magnus effect is capable of absorbing more energy from a free stream than is required to overcome surface friction of the rotor, some systems can be self powered. Devices in this category must be started by some external force. The Hanson Magnus Wind Turbine (see Chapter 4) is a good example. An ingenious internal mechanical drive arrangement extracts the small amount of energy required to spin the rotors from the main drive shaft. A motor is used to start the system but once in motion it continues to operate as long as the wind blows.

Another device illustrating a self-powered Flettner rotor system is an amusing design for a land yacht or dune sailer (Figure 10). It must be pushed to start, but once in motion, idler rollers working off the windward wheel spin the rotor in the desired direction through a friction wheel riding against the underside of the lower rotor end plate. The rotor uses the energy of the wind to give the vehicle forward motion and it in turn derives power to spin the rotor from the wheels rolling over the ground. At first glance this looks like perpetual motion, but it is no more so than a conventional dune sailer that uses cloth sails.



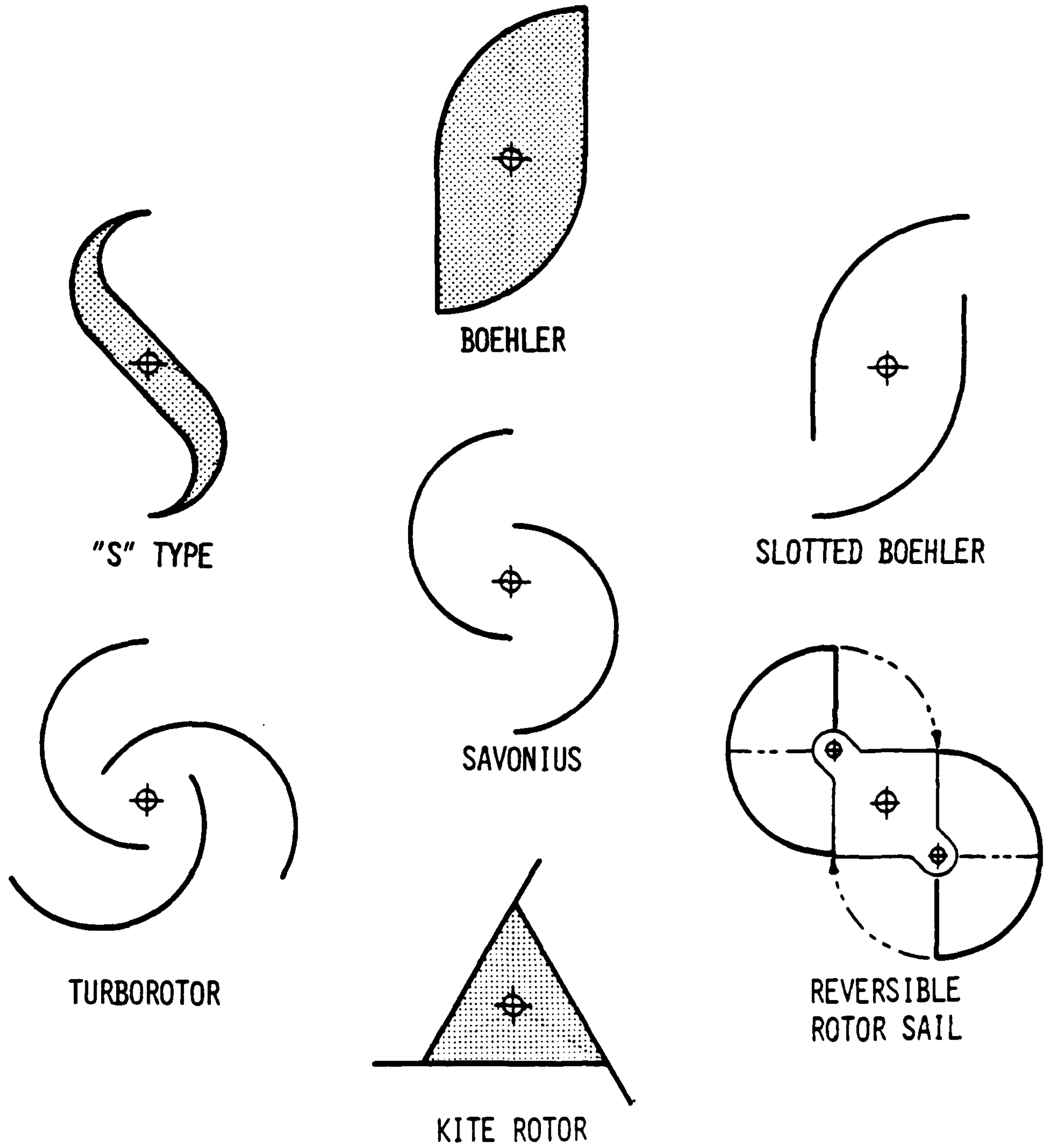
ROTORDRIVE FOR LAND YACHT

FIGURE 10

The land vehicle just mentioned was used as a simplified illustration, but the concept can easily cross over to watercraft. Suppose that a boat having a rotor sail was able to disengage its propeller shaft from the main engine and the shaft was fitted with a chain or belt connecting it to the rotor drive system. The boat would start under the power driven propeller but when the rotors developed sufficient lift for forward motion the shaft can be declutched leaving the freewheeling propeller spinning to provide force to spin the rotor. A more sophisticated, less efficient but more flexible way of doing this would be to run a generator off the propeller shaft and drive the rotor sail electrically through a bank of storage batteries. The idea is practical and it is not uncommon to find modern sailing yachts with electric generators already coupled to their propeller shafts. It wouldn't be far fetched to complete the conversion by replacing the present sails with cylindrical ones.

Besides the mechanically actuated Flettner style rotors, there exists an entire family of autorotating types (Figure 11). These also generate Magnus effect lift to some degree. Autorotors have generally been ignored in research experiments and there is little information available regarding what lift coefficient values can be expected from the wide choice of configurations. Perhaps they haven't been taken seriously because at first it seems obvious that a wind driven rotor can only have a peripheral velocity equal to the wind's speed. A velocity ratio of one would result in a coefficient of lift of only about one and therefore the autorotor would not have the advantage of compactness as compared with a conventional wing or blade. Closer study, however, reveals that the velocity ratio can be greater than unity in some instances. The well known Savonius rotor may be one of these. Its double cup cross-section shows that the wind impinges upon it at a point less than a full radius distance from the axle thus the surface actually is moving faster than the flow. The Savonius has an additional feature which enhances its torque and possibly its rotational speed. Rapidly moving fluid enters the upper half-cylinder and is deflected out the bottom so as to react against the lower portion in favor of the direction of rotation. Furthermore, most autorotors are more or less barrel shaped and no experimental work has been done to determine whether higher aspect ratios would tend to increase their coefficients of lift. This style of autorotor can be used as a sail or wing but it is most often employed as a simple vertical axis turbine and no advantage is taken of its Magnus effect qualities.

The Savonius and other two-lobed configurations share a common characteristic, they are temperamental self-starters. To insure that an autorotor will always begin rotation in a flow it should have an odd number of lobes, usually 3. The "turborotor" is similar to the Savonius rotor in that it is constructed of semi-cylinders, but 3 rather than 2. It has good lift qualities and makes an excellent self starting, autorotating windmill blade.



SECTIONS OF VARIOUS AUTOROTORS

FIGURE 11

Another aerodynamically good autorotor is composed of two quarter-circles back to back. The Boehler design has a structural advantage over the others as it can be of solid construction. It would make a fine autorotating sail if provision could be made for inverting it when tacking.

Autorotors have a high potential future as self starting wind turbine blades and as lifting surfaces on certain types of Magnus effect aircraft where the ability to glide without power is important. In spite of the handicap of lower coefficients of lift, autorotors can be used in situations where light weight and simplicity are important factors.

In spite of the autorotors' fine performance as windmill blades, all attempts thus far to use them as propeller blades have been unsuccessful. This does not mean that autorotating propellers are an impossibility but that not enough experimental work has been done to evaluate their potential.

The Magnus effect manifests itself in virtually any rotating body when placed in a cross flow but the lift is greatly enhanced when some means is used to prevent the fluid on the high pressure side of the object from migrating around the ends to the suction side. End plates or tip sealers are the most common means for preventing pressure loss. In the instances of rotor sails and rudders a vessel's deck or hull bottom can serve as a barrier provided there is not a large gap between the end of the cylinder and the hull surface.

Experiments indicate that the larger the diameter of the disk the greater the lift for a given size cylinder. Plates 2 or 3 times the rotor diameter have been tested. It must be remembered that a spinning disk absorbs a great amount of energy. Tests of rotary rudders having sealers twice the cylinder diameter used 58 percent of the horsepower needed to rotate the unit. In order to avoid wasting power, end plates are usually held to about 1-1/2 to 2 rotor diameters for most applications.

Another option is to use fixed or free wheeling disks that are not attached to the body of the rotor. There is still an unresolved question as to whether sealers that are not attached are as effective. It has been suggested that the spinning plate helps distribute the lift evenly along the length of the cylinder.

Yet another factor enters the picture when Magnus effect rudders or stabilizers are used too near the water - air interface. Ventilation can result from an insufficient pressure field above the rotor. An area of about 4 cylinder diameters is needed above a steering rotor to avoid generating whirlpool action that cancels the lift. For the same reason a rotary rudder is not as effective when part of the cylinder is exposed above the surface.

Experimentation has established that like end plate diameter, the aspect ratio of a rotor is critical to its performance. Greater length to diameter ratios result in higher coefficients of lift. There are, naturally, structural limitations to the slenderness of a rotor. Deflection or bending is not desirable for optimum service. Flettner's rotor sails had aspect ratios up to about 5-1/2. More recent applications are getting higher lift values with aspect ratios greater than 6.

Magnus effect devices are generally very forgiving. They perform predictably when the design stays within the guidelines presented in this chapter. Speed of rotation, tip seal configuration and aspect ratio are the main criteria. On the whole, driven rotors can be considered ready for general use. Henceforth, the majority of improvements will be in the mechanical and structural areas. Autorotors on the other hand call for further development to determine their full potential. The only limiting factor in the more widespread use of the Magnus effect now is the acceptance of its possibilities by engineers and designers.

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CHAPTER 4

PATENTS

GENERAL

Considering the significance of the Magnus effect, it is surprising that so few applications have found their way into everyday use. While some of the inventions seem impractical, others appear to have considerable merit.

Many Magnus effect designs are patented. The patent establishes proprietary rights and is intended to protect the invention from being used without the patentee's permission. Because Magnus effect concepts are constantly being introduced it is very important for the designer to examine the related patents.

This section identifies and describes selected Magnus effect patents. The majority of the patents chosen for this chapter are felt to have significance for marine applications although a few are included because they have been referred to in other chapters of this study. They are listed chronologically within specific categories - ship propulsion; ship steering; ship stability; energy converters; and aircraft. A more detailed description and illustrations of these and other Magnus effect patents can be found in Volume II (Appendix D) of this report.

SHIP PROPULSION DEVICES

1. A. Flettner, Arrangement for Exchanging Energy Between a Current and a Body Therein; U.S. Patent 1,674,169; issued June 19, 1928. (Application filed in Germany July 23, 1923). (Chapter 1)

Description: Anton Flettner's basic patent was apparently intended to cover every possible Magnus effect sail configuration. In the patent he points out that it may be desirable to drive the end disks at a different velocity than the cylindrical portion of the rotor. The purpose of this arrangement would be to draw the fluid medium away from the center of the rotor and provide an uniform load distribution along its length.

Assessment: The concept has some merit and should be checked out, experimentally. Both the rotor sails and windmills covered by this patent are of potential value in marine operations.

2. P.J. Jensen, Propulseur Pour Air ou Pour Eau (Propeller for air or for water); French Patent 659,443, issued to a resident of Norway, June 28, 1929. (Chapter 5)

Description: The Jensen propeller has a pair of rotors driven by bevel gears and a ring gear which is fixed to the hull of the ship. As the propeller shaft turns, the rotors spin, generating a lifting force. This arrangement would be a pusher-type propeller regardless of the direction of shaft rotation.

Assessment: Neither arrangement shown provides for a thrust reversal feature that would be desirable for use on a vessel. The propeller would have performed well and very possibly would have been more efficient than contemporary screw types.

3. W. Fork, Thrust Generating Device: U.S. Patent 4,225,286; issued September 30, 1980. Patent issued by Federal Republic of Germany, January 19, 1977. Assigned to J.M. Voith GmbH, Heidenheim, Federal Republic of Germany. (Chapter 5)

Description: This thrust generating device is a Voith Schneider cycloid propeller that uses Magnus effect rotors instead of flat vanes. The rotors are stronger, less susceptible to damage and provide increased propulsive efficiency. Other rotor drive options are an hydraulic or electric motor, or a toothed rack-and-pinion arrangement.

Assessment: The Fork invention is practical but needs end disks to improve the thrust and a means to achieve the rapid reversal of cylinder rotation. In spite of these criticisms, the Voith Schneider propeller looks promising.

4. J.L. Borg, Nozzled Magnus Effect Propeller; U.S. Patent Pending; filed November 30, 1981. (Chapter 5)

Description: The Borg invention consists of a horizontal axis propeller with two or more radially positioned rotors instead of conventional flat blades. This invention is a reversible horizontal shaft marine propeller.

Assessment: It provides more pounds of thrust per shaft horsepower and does not require end disks at the outboard tips of the rotary blades. The reversible rotor drive arrangement eliminates the need for a reverse gear at the main engine. The Borg propeller could be of value on slower vessels and workboats such as tugs.

STEERING SYSTEMS

5. W. Roos, Rudder for Ships, U.S. Patent 1,697,779; issued January 1, 1929.

Description: The vintage of Roos' steering system patent establishes that Magnus effect rudders are in the Public Domain in the United States and thus can be used by anyone without royalty agreements. The "rollers" shown in the patent are sausage shaped and lack the necessary end plates for high coefficients of lift. This would cause ventilation and result in a loss of lift and turning force.

Assessment: The Roos invention is conceptually valid. The ability to maneuver as described would be desirable in a replenishment-at-sea operation.

6. F. Weiss, et al, Method for Producing Thrust in Manoeuvering Engines for a Watercraft and a Manoeuvering Engine Contructed for the Same, U.S. Patent 4,316,721; issued February 3, 1982. Assigned to Jastram-Werke GmbH, Hamburg, Federal Republic of Germany. (Chapter 5)

Description: This invention is not strictly a Magnus effect device, but is a water jet that employs rotors for thrust enhancement and steering in one of its embodiments. The rotors replace the secondary or diffuser nozzle, resulting in an assembly that is considerably shorter in overall length. When rotated in opposite directions they control the jet expansion via the rotor speed.

Assessment: It is likely this thrust engine is still in the development stage at Jastram-Werke.

SHIP STABILIZATION SYSTEMS

7. F.V.A. Pangalila, Fixed-Angle Stabilizing Fin System; U.S. Patent 3,757,723 issued September 11, 1973. Assigned to John J. McMullen Associates, Inc., New York, NY

Description: This fixed angle stabilizing system consists of a pair of retractable rotors located below the waterline in the ship's hull. The inventor claims that his system is less complicated than the conventional variable pitch fin type anti-roll stabilizers and that being fully retractable, it would be less vulnerable to damage from flotsam.

Assessment: The motor driven, shiftable rollers would be complicated and expensive to build. The patent is assigned to a major U.S. naval architectural firm.

8. W.M. Kollenberger, deceased, Stabilizing Device for Ships, U.S. Patent 4,161,154, issued July 17, 1979. Assigned to Howaldtswerke-Deutsche Werft Aktiengesellschaft, Hamburg und Kiel, Kiel, Federal Republic of Germany. (Chapter 5)

Description: This stabilizing device employs a plurality of retractable rotors.

Assessment: This concept eliminates the problem of rapid drive reversal by using dual rotors and sliding them in and out as needed to counter the ship's roll. The stabilizer configuration is very close to what the Navy might require. It is simple, practical and sturdy. The assignee in Germany should be contacted for further information.

FLUID ENERGY CONVERTER/FANS

9. J.D. Madarasz Wind Engine, U.S. Patent 1,791,731, issued February 10, 1931.

Description: The Madarasz Wind Engine is a series of trolley cars fitted with Flettner rotor-sails and is capable of moving on a circular track. These units have a wind actuated reversing mechanism and a telescoping feature for altering the height of the cylinders.

Assessment: The concept of a wind engine is valid. The potential power available from a system similar to this invention would most likely be used in the non-military sector.

10. T.F. Hanson, Magnus Air Turbine System, U.S. Patent 4,366,386, issued December 28, 1982. (Chapters 2, 3 and 5)

Description: The Hanson patent is an updated version of the Flettner windmill but uses modern materials and aerospace engineering techniques. The machine's internal mechanical arrangement provides energy to spin the rotors automatically once the unit has been started. A full sized prototype of the turbine has been constructed and successfully tested.

Assessment: The inventor achieved his objectives of a light-weight, low-cost per kilowatt hour, storm-proof, wind turbine.

11. J.L. Borg and C.J. Borg, Magnus Effect Power Generator, U.S. Patent 4,446,379, issued May 1, 1984. (Chapter 5)

Description: The Borg vertical axis machine employs rotors that are motor driven and turn through a 180 degree arc, by means of their own lift rather than using a multilated bevel gear (See Sargent, Appendix D).

Assessment: This invention is a high-torque, low-velocity machine that is omnidirectional with respect to the wind or current. The gyro effect of the flywheel contributes to its stability in high winds.

AIRCRAFT

12. P.C. Grose, Aircraft Utilizing Magnus Effect, U.S. Patent 2,417,358, issued March 11, 1947

Description: The system is an excellent way to utilize Magnus effect without paying the drag penalty associated with rotary wings.

Assessment: Although the Grose invention may never be used on V.T.O.L. aircraft, it is a strong candidate in the realm of surface effect vessels. This idea should definitely be more throughly studied with naval applications in mind.

13. G.D. Boehler, et al, Wing Rotors, U.S. Patent 3,262,656, issued July 26, 1966, and Continuation, Wing Rotor Control Apparatus, U.S. Patent 3,439,887, issued April 22, 1969. Both assigned to Aerophysics Company, Washington, D.C. (Chapter 3)

Description: These patents relate to autorotating glider wings, their possible uses and means of maneuvering them.

Assessment: Model tests indicate that the wing rotor is a good glider and the same section can be used for other applications such as windmill blades and sails. The use of autorotor wings in lieu of parachutes for cargo delivery is plausible. Their advantages are a better glide slope and ease of control although they would use more space in a cargo plane.

14. G.G. Hirs, Aerodynamic or Hydrodynamic Element, Such as a Wing or a Blade, U.S. Patent 3,734,641, issued May 22, 1973, assigned to Nederlandse Organisatie Voor Toegepast-Natuurweten-Schappelijk Ondersoek Ten Behove Van Nijverheid, Handel & Verkeer, The Hague, Netherlands. (Chapter 3)

Description: The Hirs patent is an improvement upon De La Tour Castelcicala's invention (see Appendix D). In this version an endless belt runs on a profiled smooth body and is supported by a film of lubricant which is forced through holes under pressure maintaining the belt's rotation.

Assessment: The Hirs Magnus effect belt system shows great promise for sail propulsion. It has only one moving part, the belt traveling around a light-weight core and driven by compressed air. The element can be streamlined for drag reduction. It is a practical step beyond the original revolving cylinder idea and may lead to a new generation of more sophisticated Magnus effect applications.

CHAPTER 5

PROVEN AND POTENTIAL MAGNUS EFFECT MARINE APPLICATIONS

SAILS

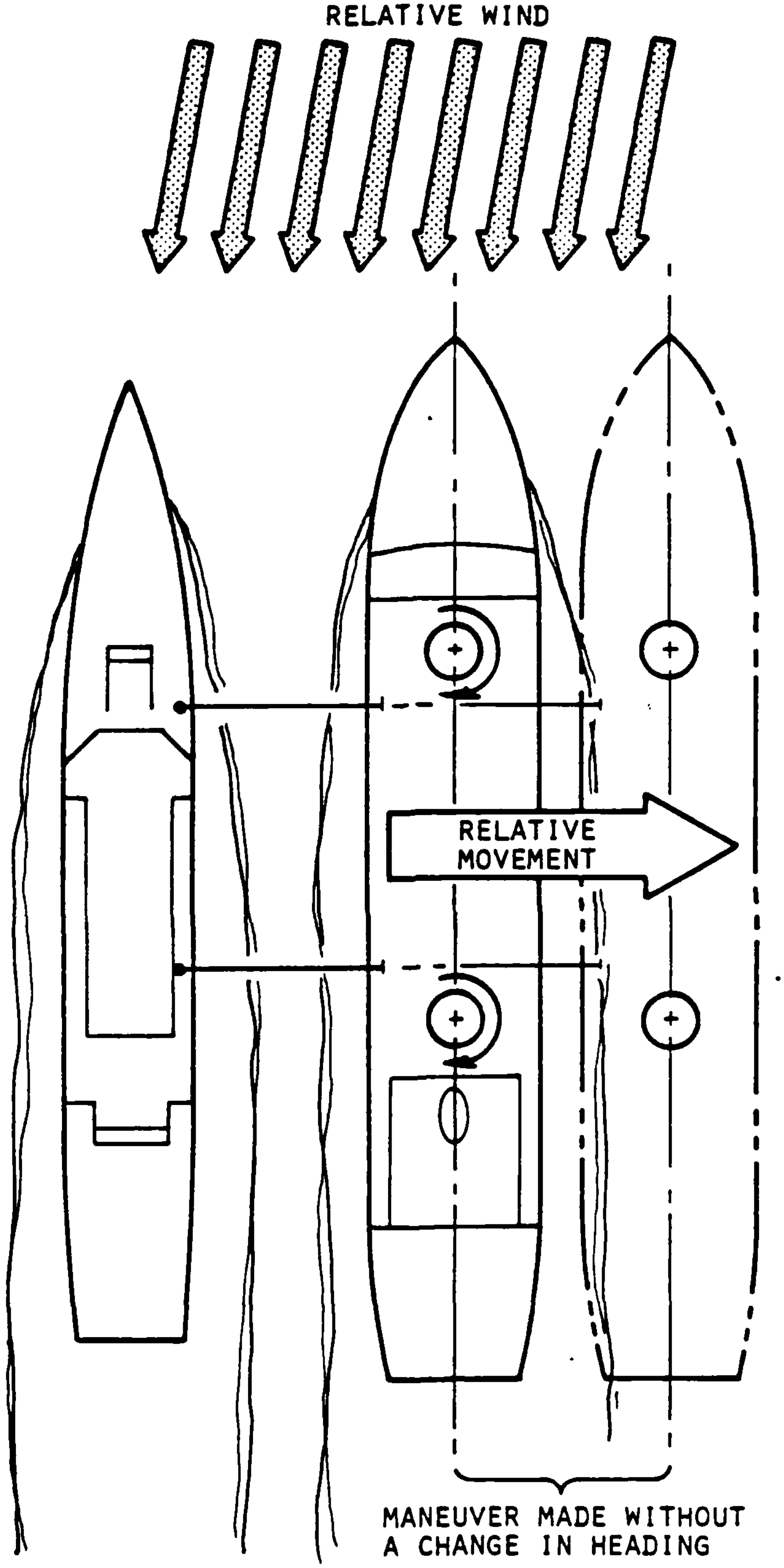
The best known marine application of the Magnus effect is the use of Flettner type rotors for wind-powered ship propulsion. A number of examples have been discussed in previous chapters proving that the concept is virtually "state-of-the-art." These include the three Flettner vessels (the Baden-Baden, the Barbara, and a yacht). Also mentioned were the Tracker of the Wind Ship Company, the twenty foot Swedish boat with a collapsible rotor and the Moulin à Vent of Captain Cousteau (Chapter 1). The developers of all of the aforementioned vessels claim satisfactory performance and have provided data regarding thrust at various headings and other useful information.

The advantages of rotor sail systems for naval cargo vessels are numerous, the most obvious being fuel conservation that would result in increased range at less cost. There would be no significant increase in crew size and little or no specialized training or "marlinspike" seamanship would be required. Recent studies indicate that vessels retrofitted with Magnus effect auxiliary sails cost less for installation and maintenance per pound of propulsive thrust than other wind powered systems.

From the standpoint of maneuverability, rotor sails can be used to steer a ship ahead or astern and are even capable of oblique or flanking movements. The ability of a ship to translate sideways without changing course could be particularly useful in replenishment-at-sea operations which are usually conducted with the wind off the bow (Figure 12).

Another possible advantage of rotor sails is their use in transverse stabilization or, at the very least, roll dampening. While it is true that any type of sail will tend to slow down a rolling motion, a Magnus effect sail can be tuned to the wind speed so as to minimize the heeling moment as well.

To date, only one retractable or collapsing rotor sail has been tested at sea. It was quite small but it proved that the concept is feasible. There is no particular reason why this idea cannot



UNREP FLANKING MANEUVER

FIGURE 12

be employed on a larger scale. Telescoping or inflatable rotors are also a possibility. Future development in this direction will doubtless make Magnus effect auxiliary propulsion even more attractive.

There are some unknown factors concerning rotorships that must be resolved before widespread use can become a reality. Foremost among these is solving the problem of vibration: determining and designing to comply with its acceptable limits. An eccentric rotating mass could cause problems ranging from crew discomfort to major structural damage. Careful design with regard to harmonics, foundation mounting and other considerations will be requisite. The mass of the moving parts must be kept to a minimum. A design in which only the surface of the barrel of the rotor is in motion is one worthwhile design approach.

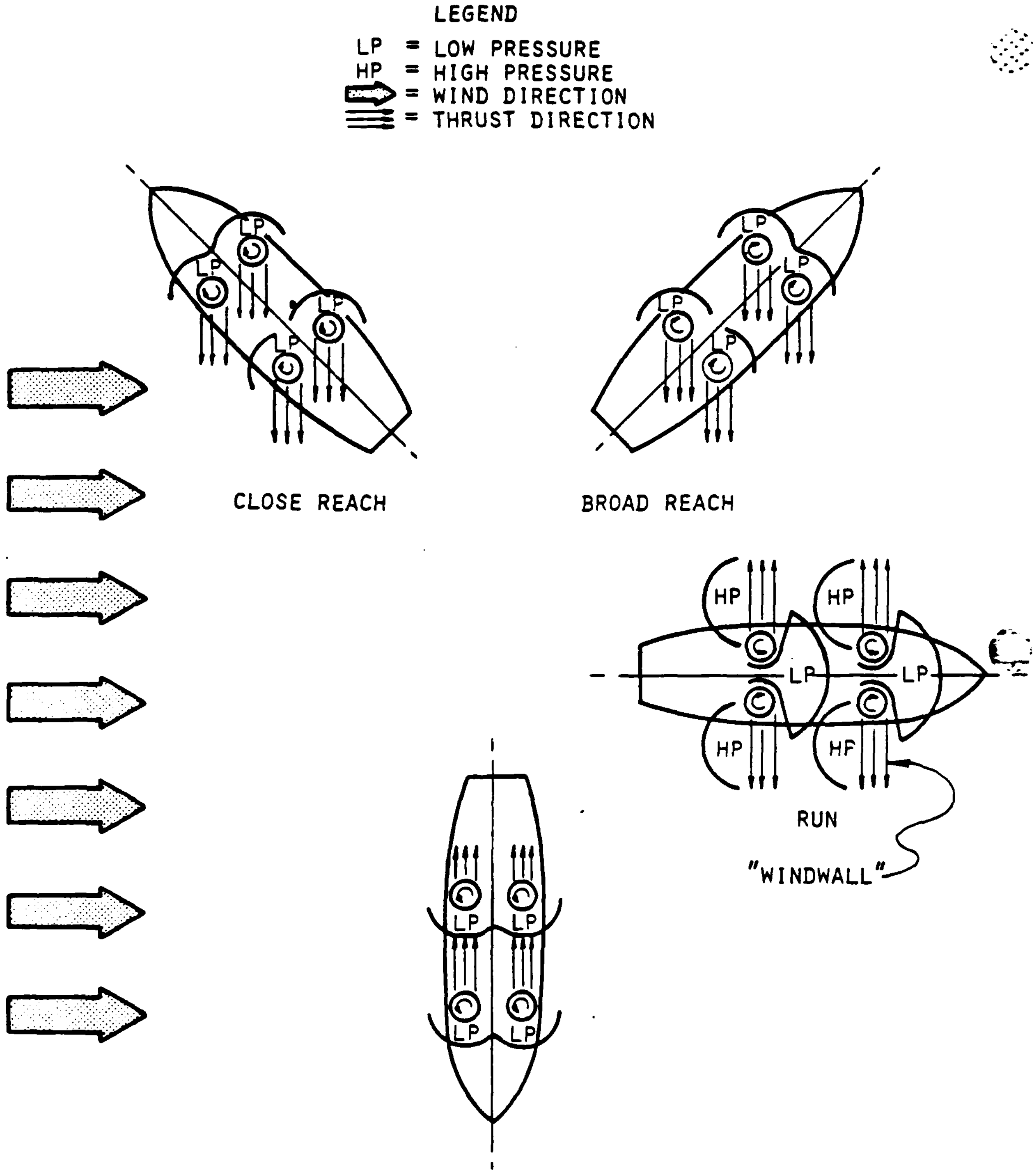
Another gray area in rotor sail knowledge is number and location of units and what multiple rotor interference might occur. The present trend is to position one or two rotors on the centerline of the vessel balanced about the "turning point" of the underwater portion of the hull. This generally turns out to be roughly one-third of the length of the waterline aft of the forward perpendicular. The symmetrical arrangement with respect to the centerline may not be desirable from the standpoint of cargo handling or accessibility to the hatches. The possibility of Magnus effect sails staggered to port and starboard should be thoroughly looked into. Other arrangements such as parallel rotors in pairs or "four-poster" configurations should be tested to determine their possible value (Figure 13).

The choice of fixed versus retractable rotors will probably be resolved along economic lines. A rotor that can be collapsed and stowed is very desirable but is going to cost more than a fixed type. Is the extra expense justified?

The selection of mechanical versus electrical versus hydraulic transmission rotor sail drive may depend upon the individual vessel installation. The U.S. Navy and the Maritime Commission could develop a family of standard modular rotor sail units with self contained power packs that could be "strapped on" cargo ships or removed as the mission might require.

From the point of human engineering a standardized rotor sail control console should be developed. The general population is not familiar with the Magnus effect and an inexperienced operator could become confused about the direction of rotation with respect to the wind unless some explicit display panel could define the forces involved.

Surface texture is still another little understood factor in Magnus effect design. Although smooth cylinders are known to work well as rotor sails, a slight reverse lift has been noted at very low velocity ratios. Some experimenters claim that this does



"FOUR POSTER"
ROTORSHIP SAIL ARRANGEMENT
FIGURE 13

not occur on rotors having a rough surface. It has also been suggested that a rough surface increases lift to a certain extent. The trade-off is that additional energy is needed to spin the rotor. More experimentation is needed in this area (see Chapter 8).

Another unknown characteristic of the rotor sail to be mentioned is its radar signature. How will a rotorship appear on hostile radar screen? Should certain materials be avoided in rotor construction that may make cargo vessels too visible? No work has yet been done on this aspect of the naval use of rotor sails.

STEERING

Ship steering is the second proven marine application of the Magnus effect. Four known ships and boats of various types have recently been fitted with rotary rudders in the United States and West Germany. There may be others in different countries that have not been publicized.

The most noticeable feature of a rotary rudder is its simplicity and its space saving compactness. Since there is no tiller or hyraulic cylinder, the rotor actuating drive is relatively small taking up very little space in the steering compartment. The components: a flanged cylinder shaft, bearings and motor, are common structural and mechanical elements so the construction cost is low when compared with the expense of fabricating a modern semi-balanced rudder having an airfoil cross-section.

A rugged steel cylindrical rudder is much less vulnerable to damage from debris or floating ice than is the conventional blade type. Aside from running aground at high speed, it is difficult to think of a situation that would be hazardous to a rotary rudder.

Magnus effect steering significantly increases maneuverability because it acts in a direction that is perpendicular to a ship's course, greatly reducing the radius of the turning circle. It is not necessary to anticipate the helm, it is either on or off and for this same reason it is almost impossible lock a vessel into a dangerous turn in case of mechanical failure. If the rotor drive happens to break down the ship will continue on a straight path and can be avoided by other water traffic until stopped. Maneuvering astern is enhanced because the cylindrical rudder does not starve the propeller of green water in the way a conventional rudder does and is not subject to excessive rudder shaft torsion or failure due to rearward shift of the center of pressure.

Retractability is another desirable characteristic of cylindrical rudders. It means that a ship with conventional steering could carry a compact and relatively inexpensive Magnus effect retractable unit for emergencies and additional low speed maneuvering power. A retractable steering rotor might be housed forward as a bow rudder. Unlike blade rudders the cylindrical kind can be used for effective bow steering because they do not act as a flap underway. Bow and stern Magnus effect rudders could enable a ship to flank obliquely without a change in heading. This convenient maneuver would be used in a situation such as overtaking a slower vessel and even for collision avoidance.

For certain hull configurations a modular Magnus effect steering unit can be installed in a watertight well that extends from the deck to the bottom of the hull. This steering package can be replaced for maintenance and repair without drydocking the vessel (Figure 14).

A standard rudder develops an increasing drag component as the rudder angle becomes greater. Loss of thrust as well as diminished speed occur when completing a turn. The drag generated by a Magnus effect rudder does not increase significantly regardless of the turning force being developed. A ship equipped with steering rotors does not slow down during a turn and considerable fuel saving can be realized.

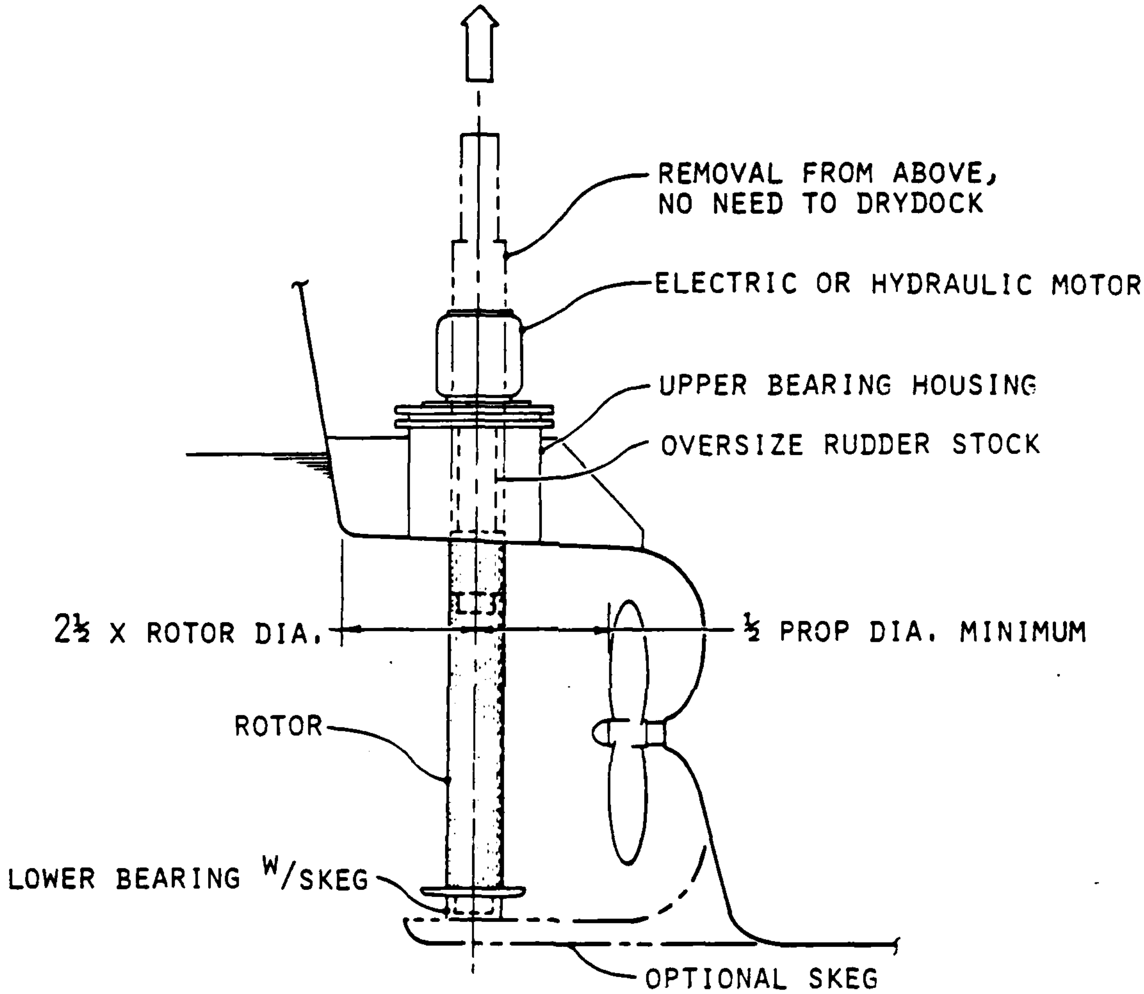
Rotor steering is particularly attractive for very large cargo carriers because the system can easily be driven by an electric motor.

Some areas calling for further study regarding Magnus effect steering systems are: the inter-reaction between twin rudders; optimum end plate design; and the optimum distance for locating steering rotors with respect to a vessel's propeller and hull.

GENERATORS

The third category of proven Magnus effect applications is that of energy converters or windmills and waterwheels. The Flettner rotor windwheel, the Madarasz wind engine (Chapter 4) and the Hanson Magnus air turbine system (Chapter 4) are examples of practical wind energy converters that have been constructed. Water driven systems have been proposed but it is not known if any actually exist.

The Magnus turbine should be considered as a possible source of auxiliary or emergency power to drive rotorsails. Again it is



MAGNUS EFFECT RUDDER ARRANGEMENT

FIGURE 14

the compact nature and high torque capability that would influence the choice of a rotor bladed windmill for this purpose (Figure 15).

Vertical axis Magnus effect converters are in the development stage and they look like a plausible means for extracting energy from a tidal flow. They have two unique characteristics that favor them for this use. First, a Magnus effect system functions on flow velocity and not hydraulic pressure as most water driven generators do. For this reason no dams need to be built and the units can work in fairly shallow water. Second, the omnidirectional capability of a vertical axis machine is ideal for use in a tidal current that normally changes direction four times a day (Figure 16).

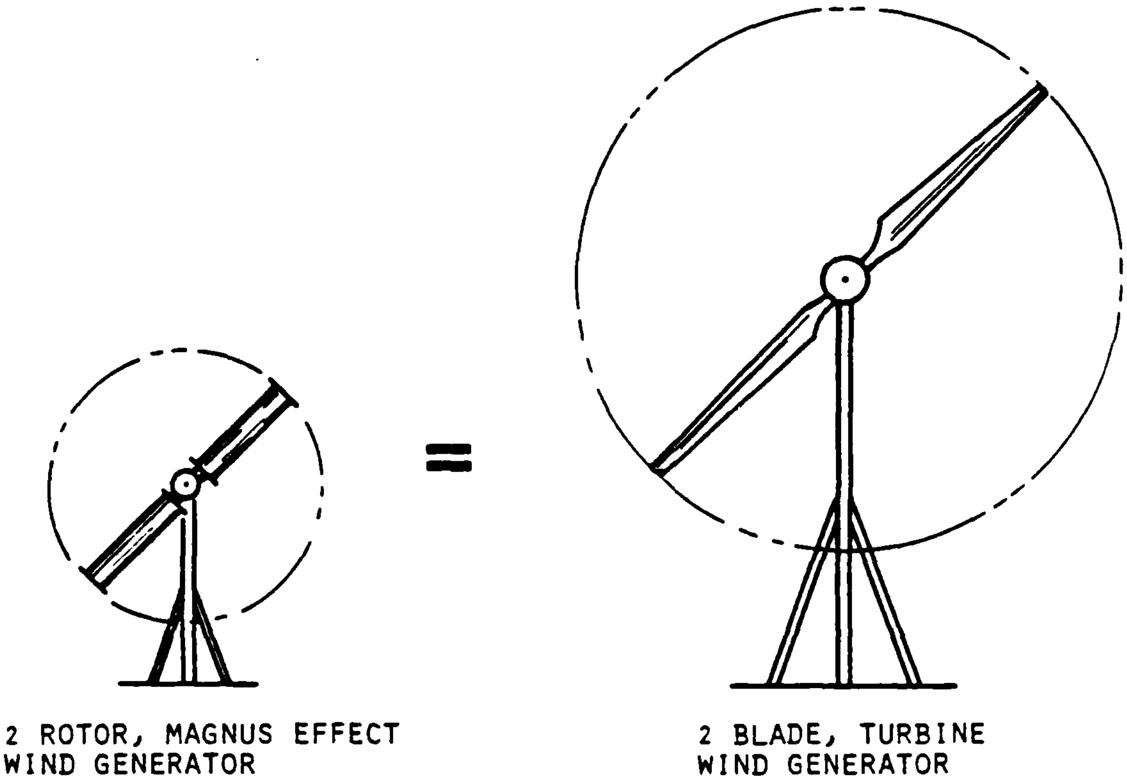
PROPELLERS

Magnus effect propellers are closely related to wind turbines but for some reason have not been developed past the experimental stage. Models have been constructed that work well, proving that the principle is valid. Calculations indicate that the thrust that can be developed by a rotor blade propeller is much greater than that of a screw propeller of similar diameter. On paper, at least, the Magnus effect type could develop twice as many pounds of bollard pull per horsepower.

There are three varieties of horizontal axis rotor propellers that may be substituted for existing ones. They are the geared or friction drive type, the kind with hydraulic or electric motor driven rotors and the autorotating type. No autorotor propellers have yet been successful and by nature would produce the least thrust.

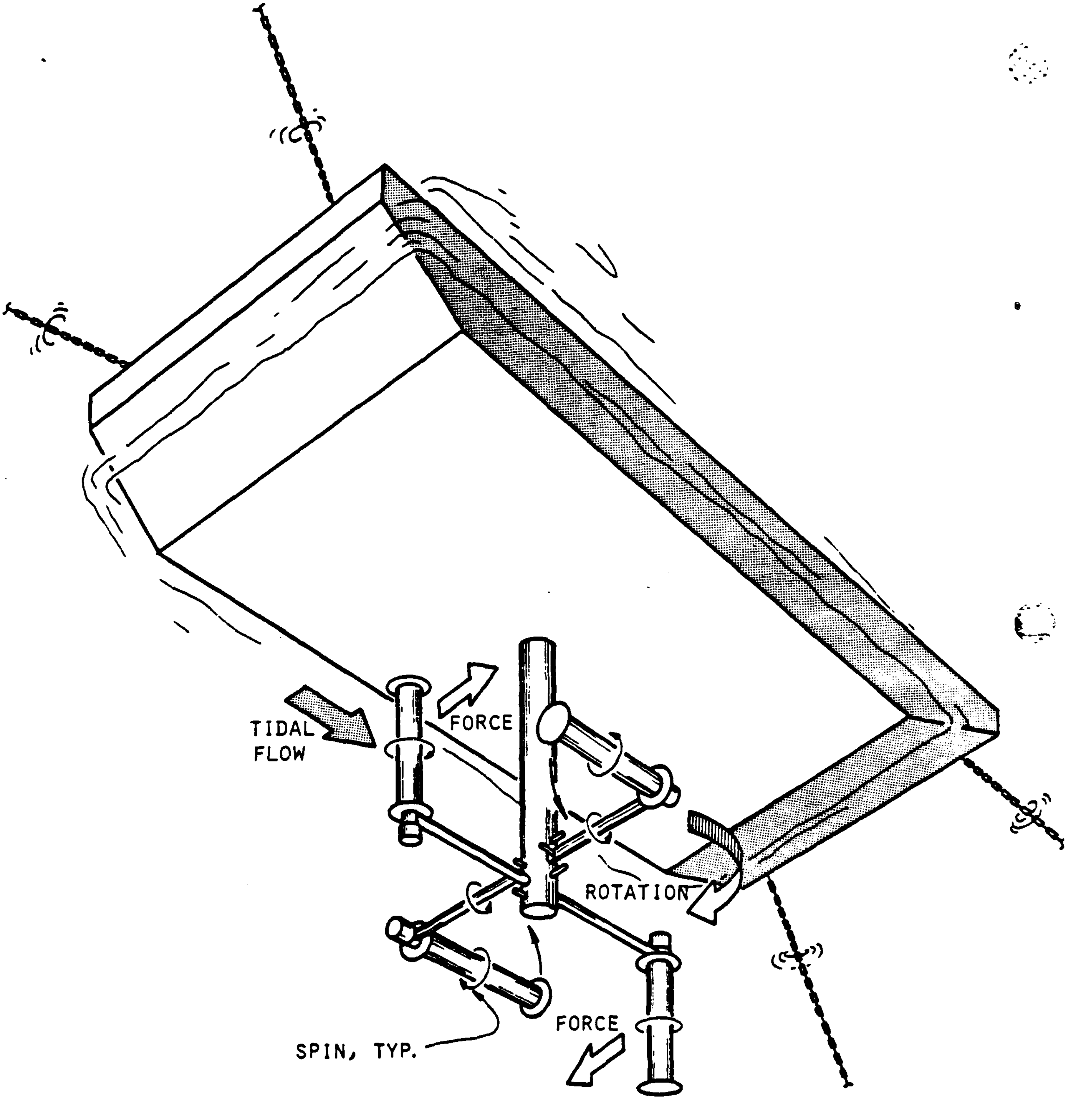
Earlier Magnus effect propeller patents such as Jensen's (Chapter 4) generally relate to gear driven rotor systems, often with no regard for reversal of direction. It is difficult to achieve high enough rotational velocity at the tip of the rotor for optimum lift coefficients when it is driven by contact somewhere near the hub because of the great difference between the rotational speeds of the shaft and the rotor. The nozzled rotor prop overcomes this deficiency by taking advantage of high tip velocity to spin the rotors at a greater speed thereby developing maximum lift along the entire length of the rotor (Figure 17).

The other horizontal axis propeller option has motors mounted at the hub which are coupled directly to the rotors to spin them. These motors need not be very large to perform this function. An advantage of this arrangement is that it is reversible by means of the propulsion engine's gear box, making it a favorite choice for retrofitting (Figure 18).



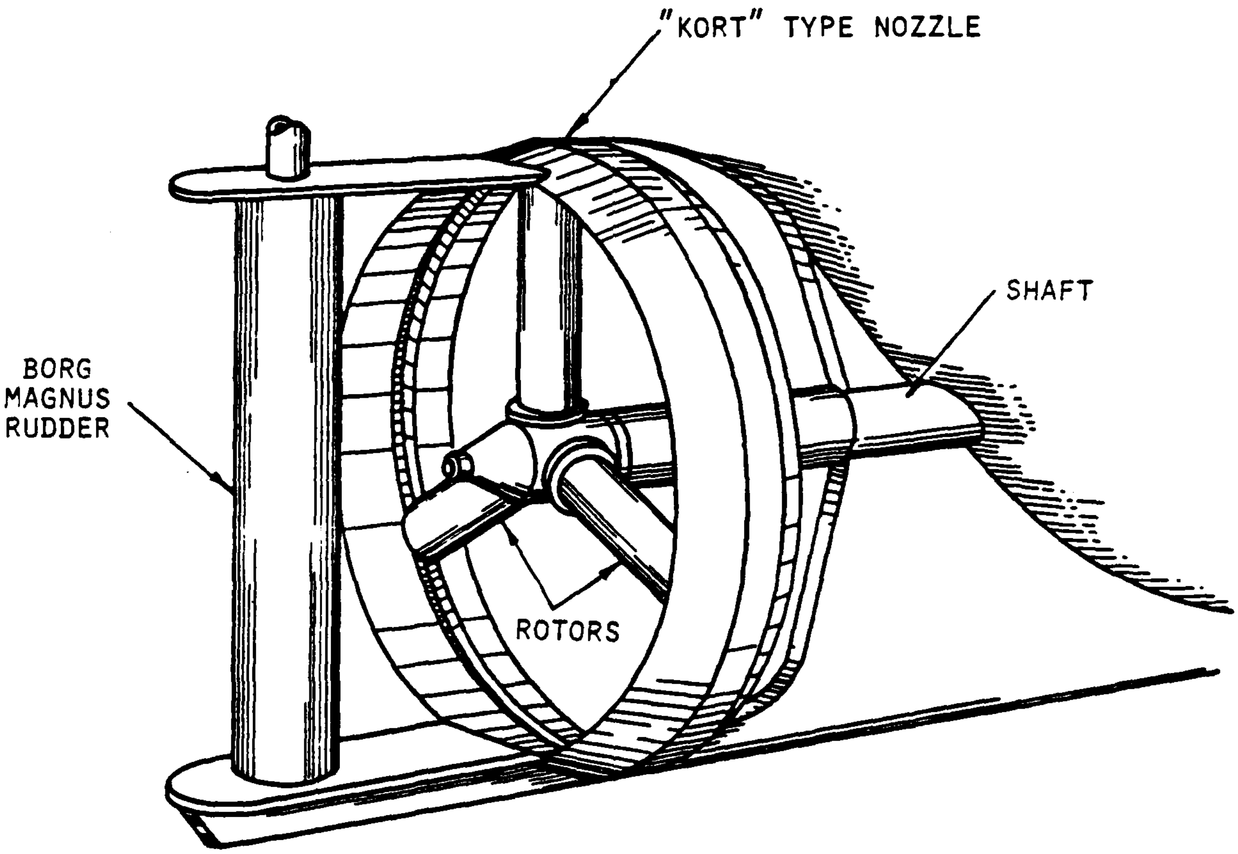
SIZE COMPARISON OF MAGNUS EFFECT AND
TURBINE WIND GENERATORS OF EQUAL POWER

FIGURE 15



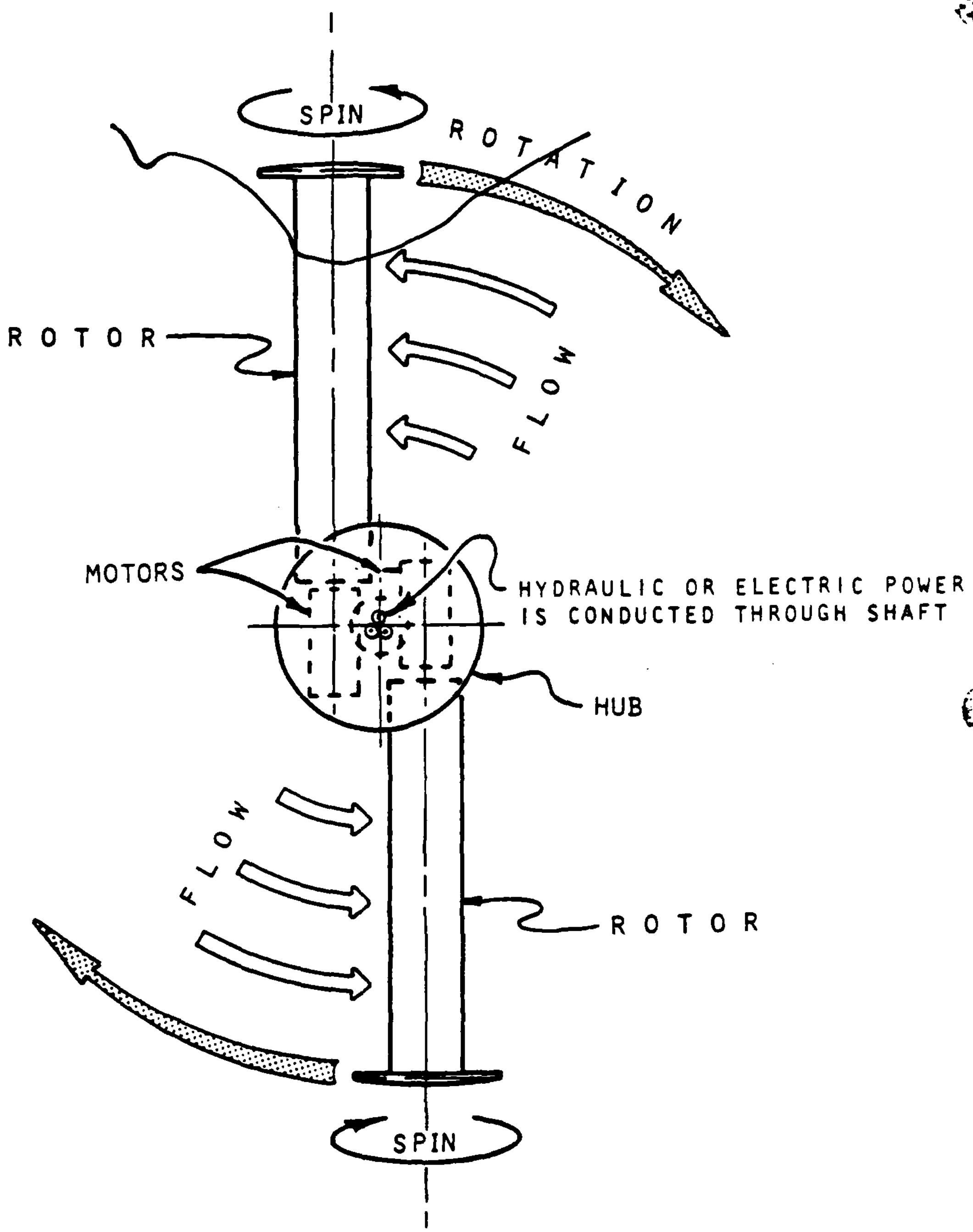
MAGNUS EFFECT TIDAL FLOW ENERGY CONVERTER

FIGURE 16



NOZZLED ROTOR PROPELLER WITH MAGNUS RUDDER

FIGURE 17



MOTOR DRIVEN PROPELLER
(VIEWED FROM ASTERN)
VESSEL IN FORWARD MOTION

FIGURE 18

A vertical axis propeller has been patented which is a Magnus effect version of the famous Voith-Schneider propulsion system (Chapter 4). The cycloidal propeller calls for a special hull configuration and it is an unlikely candidate for conversion of existing vessels.

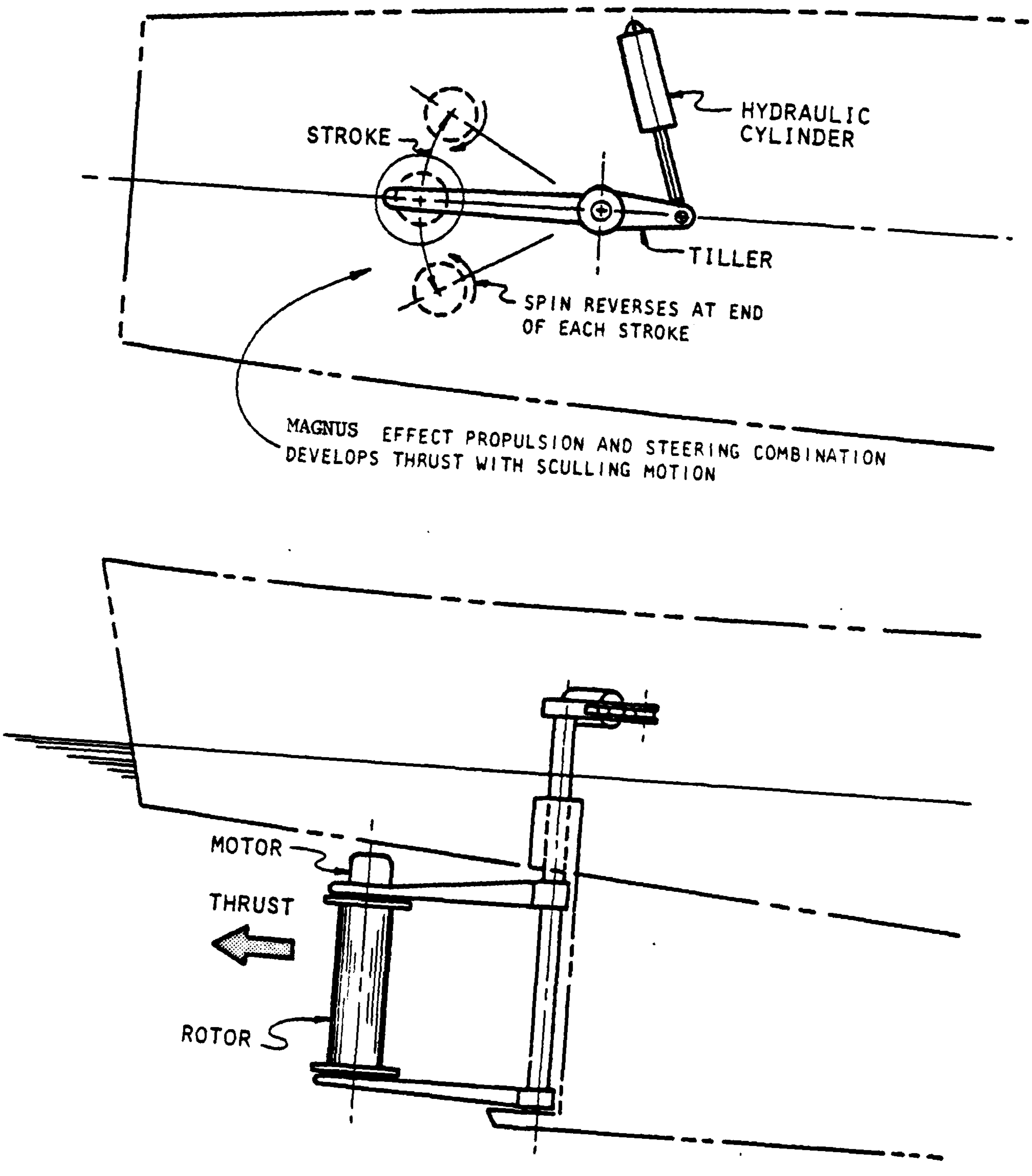
There are several other less orthodox approaches to Magnus effect ship propulsion that should be mentioned. One is the Weiss Maneuvering Engine that uses rotors in conjunction with a water jet propulsion system to enhance thrust as well as to steer (Chapter 4).

Another idea somewhat along the same lines combines the rotary rudder and propeller into a single unit. A motor driven cylinder is mounted vertically on a pair of arms at the stern. Hydraulic cylinders stroke the arms from side to side fishtail fashion creating the flow. The direction of rotation of the cylinder is reversed at the end of each stroke, producing thrust to move the vessel. Steering can be accomplished by allowing the spinning rotor to dwell for a moment on the side appropriate for the turn, before its direction is reversed. Unconventional as it is, the reciprocating rudder-propeller eliminates a large amount of fuel consuming appendage drag (Figure 19). It may have a place on vessels for which propeller noise is an important factor.

Magnus effect bow thrusters are another possible use for rotor propellers. Here the nozzled type would be advantageous because of high thrust characteristics.

In addition to the ability of Magnus effect propellers to produce more thrust, there are also other advantages that should be enumerated. It may be possible to replace rotor components underwater without dry docking. Initial and repair costs could be less because these propellers can be of steel fabricated construction, not enormous foundry castings using expensive exotic metals. Magnus effect lift is always positive and there is no propeller slip. The concept of pitch is not valid and blade selection is greatly simplified since it is simply a matter of length and diameter. Magnus effect propellers have no blade leading edge and produce maximum thrust for any given rpm either ahead or astern. The unconventional reciprocating and jet systems, such as the Weiss-Jastram system (Chapter 4), combine propulsion and steering into a single unit resulting in less resistance and greater efficiency.

There are some anticipated engineering problems to be overcome before Magnus effect propulsion can become a reality. The selection of proper materials for construction and the choice of optimum rotor configurations and aspect ratios are examples. While it is known the rotor propeller will work when static, that is used as a fan, future tests must be made to find out the effect in



RECIPROCATING RUDDER-PROPELLER

FIGURE 19

a moving stream. In other words, as a ship moves forward through the water the angle of the flow impinging upon the rotor will change and it is not yet known if this will cause problems.

STABILIZERS

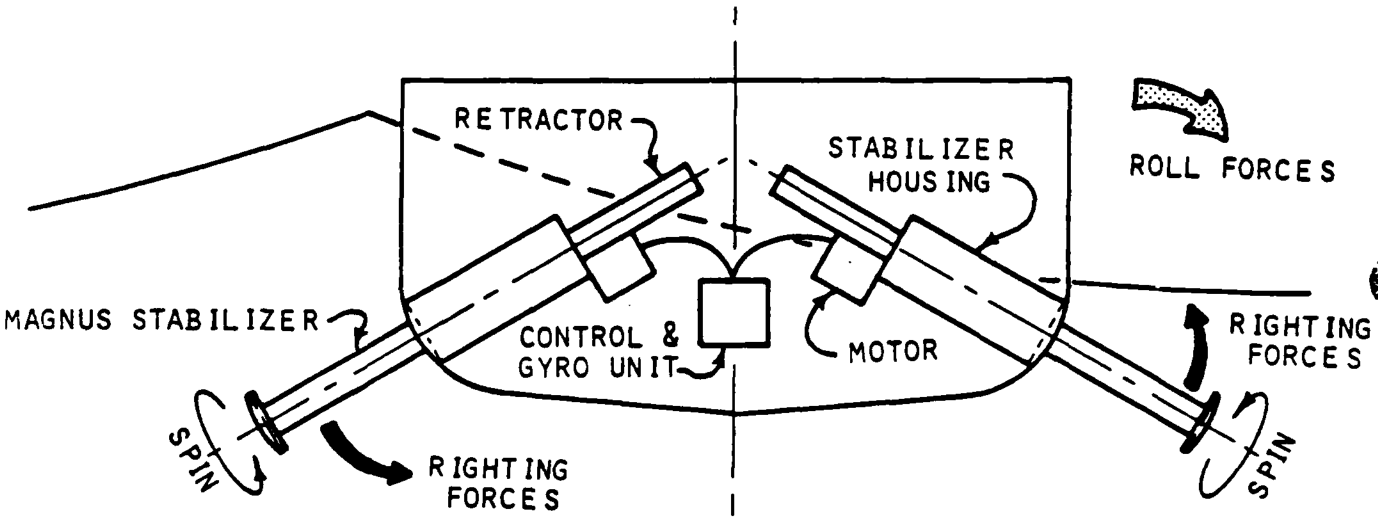
Magnus effect stabilizer patents were summarized in Chapter 4 but so far as is known, no such system has ever been installed on a ship. Nonetheless rotor stabilizers appear to have a number of advantages over inertial and fin type systems. A rotor stabilizer would be much smaller, stronger, simpler and less expensive. Magnus effect steering system technology can be applied directly to the design of stabilizers. Existing fin stabilizer sensing and control systems may be adapted directly for rotors by changing their output from "angle of attack" to "direction of rotation". Rotor stabilizers are fully retractable, not merely folded inboard and hence are not vulnerable to damage from debris or ice. Rotors may be extended and idled at a surface velocity of slightly less than the ship's speed and act as "drag-invisible outriggers" due to the Barkley Phenomenon (Figure 20).

There are some possible problem areas relating to Magnus effect stabilizing systems that bear mentioning. Can drive mechanisms be developed that will react quickly enough to match the ship's period of roll? What will be the best location for rotor installation to prevent them from steering the ship rather than stabilizing it? What distance from the surface must be maintained to avoid ventilation? How are the forces involved in a ship's rolling behavior determined so that a properly sized system can be designed?

EXAMPLES OF USES OF THE MAGNUS EFFECT OTHER THAN CONVENTIONAL VESSELS

The proven and potential Magnus effect marine applications discussed thus far, namely, rotor sails, steering systems, energy converters, propellers and stabilizers are of possible value for all naval surface ships. It is now time to mention some applications that may be useful to naval activities in general. Retractable Magnus effect steering units could be used on submarines for emergency service and to improve low speed maneuverability. It is well known that modern nuclear powered submarines are difficult to handle at low speed and on the surface; a retractable steering rotor could correct this deficiency.

Tidal flow, vertical axis, Magnus effect energy converters would be useful to tap tidal currents to provide electrical energy for shore facilities and desalinization units.



MAGNUS EFFECT STABILIZER SYSTEM
(SYSTEM SHOWN OVERSIZE FOR CLARITY)

FIGURE 20

Magnus effect rotors could be adapted for use as very compact and controllable minesweeping paravanes.

Autorotating stabilizers that can be stowed in small packages could be used for life boats and rafts. These have the additional feature of being able to translate the motion of waves into forward propulsion if rigged in a particular way. Another useful piece of lifesaving equipment would be an autorotating Magnus effect kite aerogenerator and radar reflector.

Rotor lifting surfaces for high speed patrol boats and landing craft are a possibility.

Finally Magnus effect aircraft drones such as the Van Dusen aircraft (Chapter 2), might be used for surveillance, cargo transfer and even fire fighting.

CHAPTER 6

METHODS AVAILABLE TO DETERMINE MAGNUS EFFECT FORCES

The transverse force L (lift) acting on the cylinder with circulation in a uniform flow may be shown by the equation:

$$L = \rho \cdot \Gamma \cdot V \cdot b \qquad \text{(equation 6.1)}$$

Where

ρ = mass density of fluid
$\Gamma = 2\pi c$ = strength of circulation flow
V = velocity of uniform stream
c = constant = $r \cdot v$
b = length of cylinder or span
r = radius vector (drawn from the center of the cylinder to its surface)
v = velocity at any point which is everywhere normal to radius vector (in this case the surface velocity)

Equation (6.1) is known as KUTTA-JOUKOWSKI THEOREM OF LIFT, and is one of the great generalizations of mechanics since it applies to all bodies regardless of their shape, the shape factor being contained in the circulation factor "Γ" (Ref. 28). In dealing with Magnus effect rotors the cylinder itself may be regarded as the "vortex core".

In an ideal fluid used in inviscid theory, viscosity is ignored, no energy is dissipated into friction and subsequently heat. The energy conversion between pressure energy and kinetic energy involves velocity and pressure changes only (Figure 21).

The expression for the dimensionless lift coefficient, C_L is

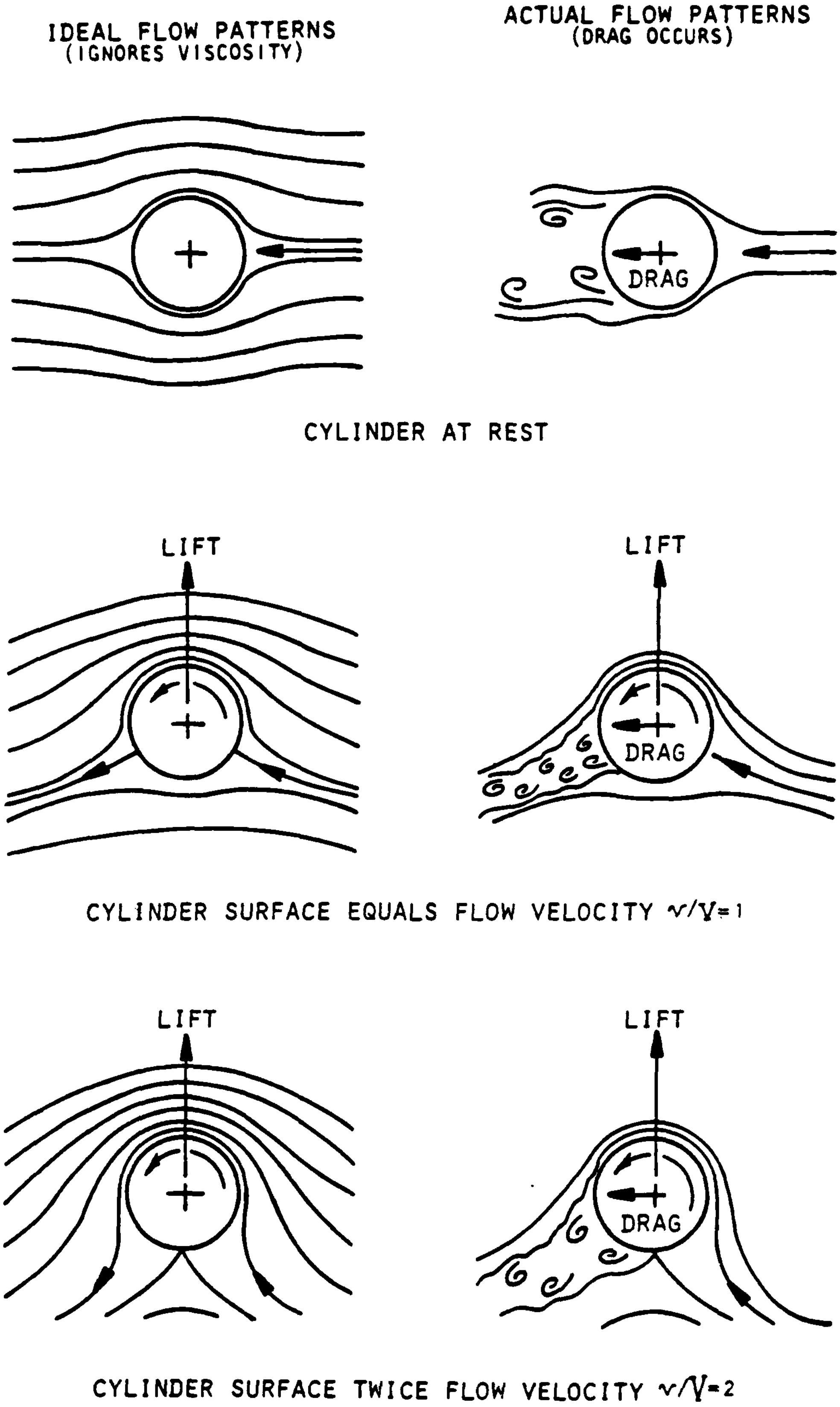
$$C_L = \frac{L}{\frac{1}{2}\rho A V^2} \qquad \text{(equation 6.2)} \quad \text{(Ref. 28)}$$

Where

A = projected area (in the case of the cylinder $2 \cdot r \cdot b$)

Substituting L for the KUTTA-JOUKOWSKI equation (6.1)

$$C_L = \frac{\rho \Gamma V b}{\frac{1}{2}\rho A V}$$



BEHAVIOR OF A CYLINDER IN PARALLEL FLOW
FIGURE 21

Then substituting for Γ and A

$$C_L = \frac{\rho 2\pi r v V b}{\frac{1}{2}\rho 2 r b V^2}$$

It is reduced to

$$C_L = 2\pi\frac{v}{V} \qquad \text{(equation 6.3)}$$

or the coefficient of lift of a rotating cylinder in an ideal fluid. This theoretical value of the lift coefficient C_L is much higher than has been practically obtained by experiments in real fluids. This is primarily due to viscosity, which is responsible for the large wake often observed and therefore for the associated pressure drag. Since drag cannot be accounted for by a theory based on an ideal fluid concept, the drag coefficient can only be established empirically by measurement. The real lift coefficient may also be obtained by direct measurement.

All this would seem to indicate that theoretical coefficient of lift is of little use in selecting the dimensions of rotors but the results of a majority of experiments tend to fall within an envelope between 50% and 25% of the theoretical C_L. This information can be used in choosing rotor proportions during the preliminary design stage, later tests would confirm the actual values. Approximations within the velocity ratio range of 2 to 5 would approach:

$$C_L = \pi\frac{v}{V}$$

for high aspect ratio cylinders having generous end plates and be closer to:

$$C_L = \frac{1}{2}\pi\frac{v}{V}$$

for the stumpier designs. There seems to be no convenient engineering recipe for precisely predicting Magnus effect lift for cylinders of untested proportions, but then this is also true of conventional airfoil sections.

The recommended method for estimating the C_L of an untested rotor is to refer to the family of experimental curves and try to find one of similar proportions. If the aspect ratio and/or end plate diameter are greater, then so too will be the lift coefficient and the opposite will also be true. There have been many Magnus effect investigations since Flettner's time so numberous C_L curves are available for reference.

These curves are plotted on a grid whose vertical ordinate is the lift coefficient C_L and whose horizontal ordinate is the ratio of cylinder surface to free stream flow velocities v/V. There is generally little difference in lift values among the curves for v/V ratios of less than 1.5. The majority of the tests were carried out in wind tunnels but it is reasonably safe to assume that they are also valid for a liquid medium (Figures 22 - 25).

Since there are so many curves, their description is given in tabular form for convenience. They have been plotted on three sheets for easier interpretation.

The family of experimental curves clearly shows how rotors of conventional design fall in the envelope defined by $C_L = \pi v/V$ and $C_L = \frac{1}{2}\pi v/V$ (curves B and C). It also points out the relationship between larger aspect ratios and higher coefficients of lift. The curves G and H compare Flettner rotors with and without endplates, showing a 100% increase in lift. Curves J and K are of identical cylinders but the rough surface texture of J gives it a markedly improved performance.

In order to compute the lifting force developed by a rotor in a particular velocity free stream, one needs to know its lift coefficient (from the C_L curves), its projected area, (length x diameter) and the mass density of the fluid medium ρ ("rho"). Values for mass density of a fluid are derived from the expression:

$$\rho = \frac{\text{weight per unit volume}}{\text{acceleration due to gravity}}$$

or

$$\rho = \frac{\text{pounds per cubic foot}}{g} \qquad \text{(equation 6.4)}$$

Obviously the value of ρ is going to vary somewhat due to such factors as temperature, altitude and salinity but for design purposes the following generalizations are acceptable:

$$\rho \quad \text{sea water} = \frac{64 \text{ lbs/cubic ft}}{32.2 \text{ lbs/sec}^2} = 1.9875 \text{ slugs/cubic ft}$$

$$\rho \quad \text{fresh water} = \frac{62.4 \text{ lbs/cubic ft}}{32.2 \text{ lbs/sec}^2} = 1.9379 \text{ slugs/cubic ft}$$

$$\rho \quad \text{air at sea level} = \frac{0.075 \text{ lbs/cubic ft}}{32.2 \text{ lbs/sec}^2} = 0.0023 \text{ slugs/cubic ft}$$

The lifting force of a rotor can be determined from the accompanying curves and solving equation 6.2 for L.

$$L = \frac{C_L A \rho V^2}{2} \qquad \text{(equation 6.5)}$$

EXAMPLE:

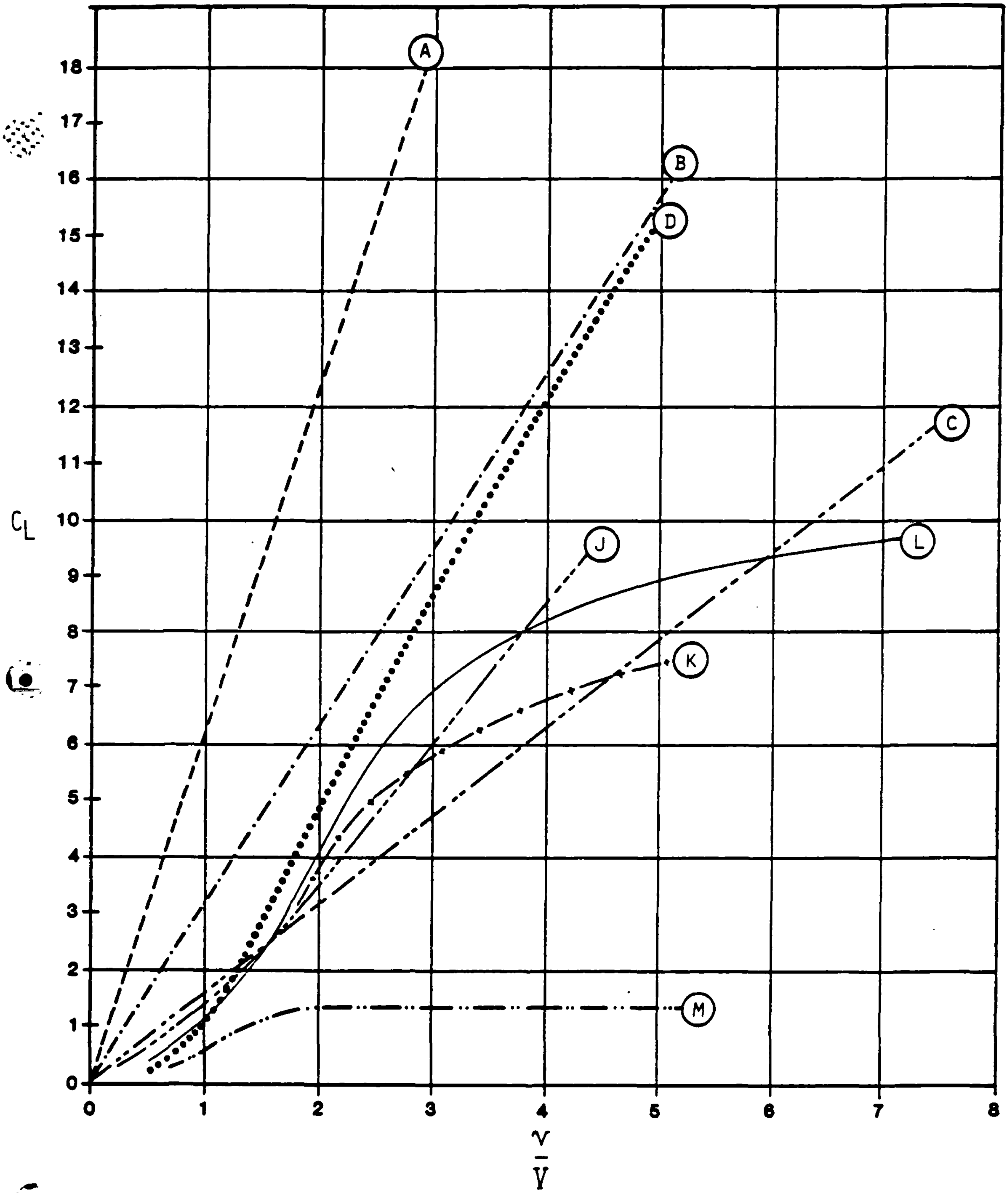
Find the force produced by a rotary rudder 6'-0" long and 1'-6" in diameter having 3'-0" diameter end plates whose

TABLE OF MAGNUS EFFECT EXPERIMENTAL C_L AND C_D CURVES

$*de/d = \frac{\text{end plate dia}}{\text{cylinder dia.}}$

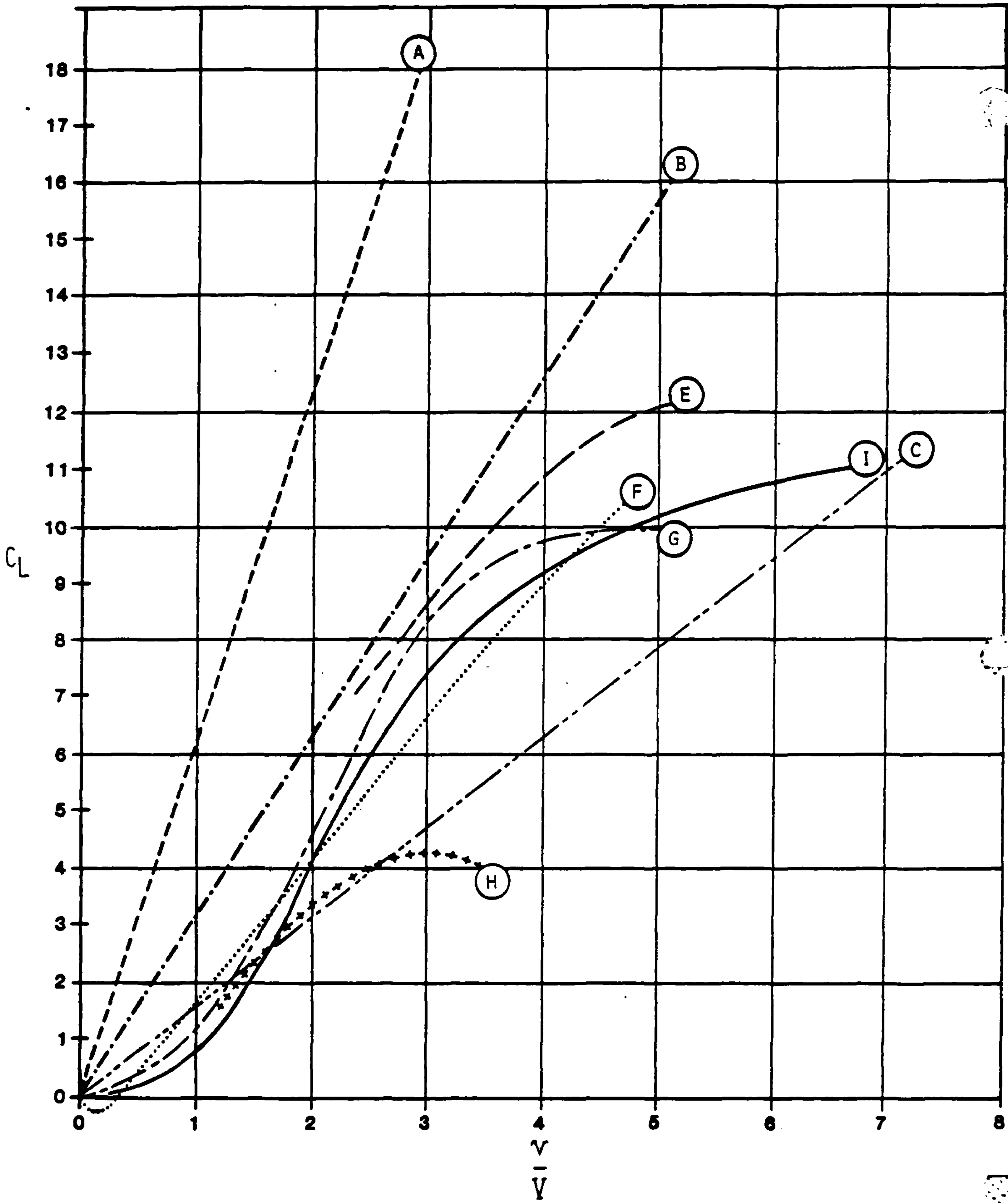
CURVE	SHEET	INVESTIGATOR	REF. NO.	ASPECT RATIO	de/d*	REYNOLD'S NUMBER	REMARKS
A	1,2	ideal fluid $C_L=2\pi v/V$		∞	-	∞	inviscid theory
B	1,2	50%A, $C_L=\pi v/V$		∞	-	∞	reference curve
C	1,2	25%A, $C_L=\frac{1}{2}\pi v/V$		∞	-	∞	reference curve
D	1	THOM	26	12.5 & 26	3	$5.3\text{-}8.8\times10^3$	approaches curve B
E	2,3	WINDSHIP	16	6.2	1.58	4.5×10^5	full size measured at sea
F	2,3	REID	31	13.3	NONE	$3.3\text{-}11.6\times10^4$	C_L equivalent to shorter cylinder with plates
G	2,3	GOTTENGEN	32	4.7	1.7	5.2×10^4	Flettner sails
H	2,3	GOTTENGEN	32	4.7	NONE	5.2×10^4	Flettner sails without end plates
I	2,3	BORG	appendix B	4.0	2	11.15×10^4	tested in fresh water
J	1	THOM	26	5.7	NONE	$3\text{-}9\times10^4$	rough surface (sanded)
K	1	THOM	26	5.7	NONE	$3\text{-}9\times10^4$	smooth surface
L	1,3	SWANSON	24	∞	NONE	3.5×10^4 3×10^5	
M	1	SWANSON	24	2	NONE	5×10^5	continous end sections

FIGURE 22



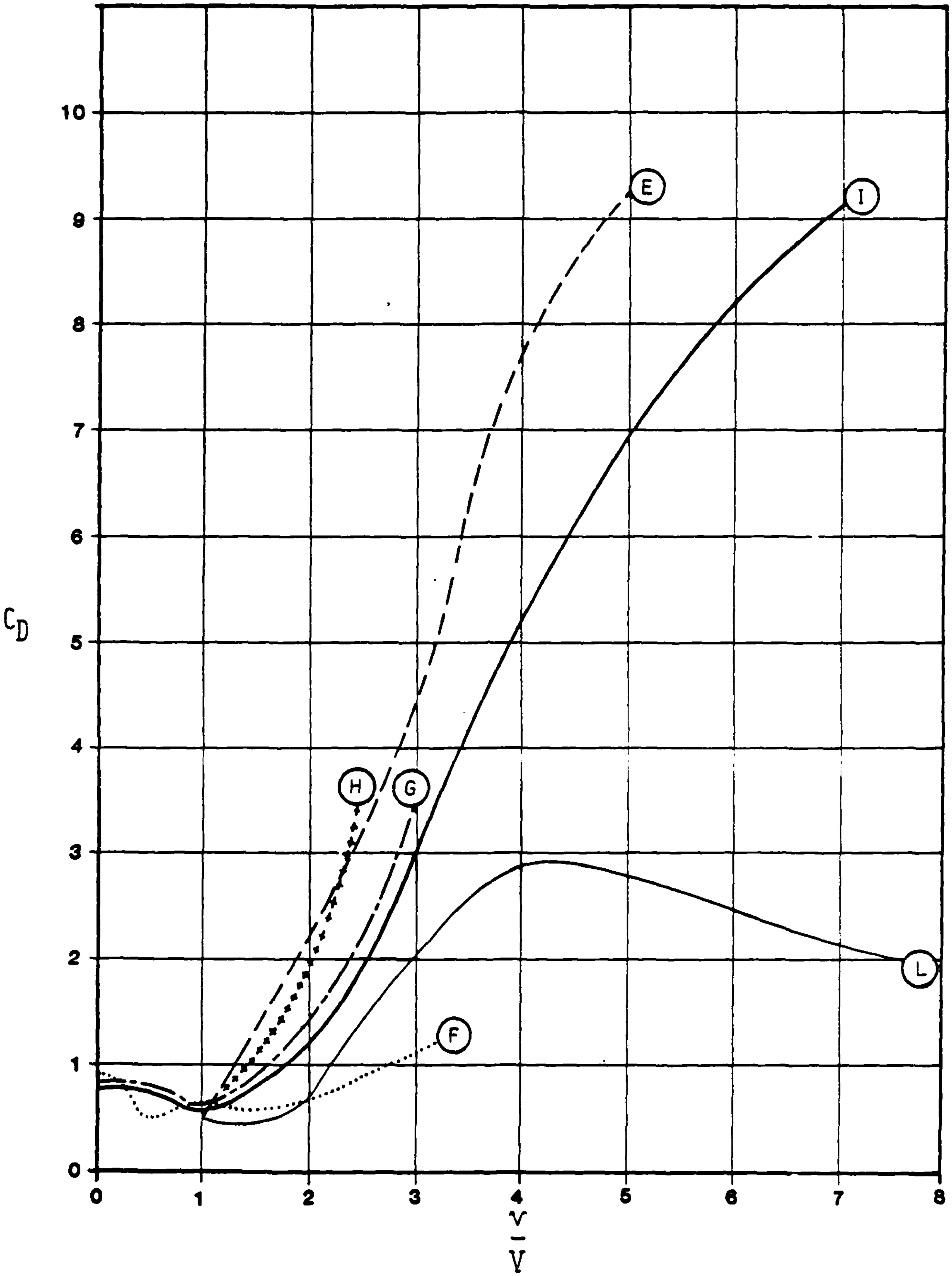
MAGNUS EFFECT COEFFICIENTS OF LIFT (SHEET-1)

FIGURE 23



MAGNUS EFFECT COEFFICIENTS OF LIFT (SHEET-2)

FIGURE 24



MAGNUS EFFECT COEFFICIENTS OF DRAG (SHEET-3)

FIGURE 25

peripheral velocity is 3 times that of the boat's propeller wake of 8 knots.

C_L = 8.4 at v/V = 3 (from curve "I")
A = 6.0' x 1.5' = 9 sq. ft.
ρ = 1.94 (for river water)

$$L = \frac{8.4 \times 9 \times 1.94 \times 182.36}{2} = 13,372.8 \text{ lbs.}$$

The drag produced by a rotating cylinder also increases with the surface velocity. This is caused partly by the entrained fluid surrounding the rotor and partly by the wake it generates along its high pressure side.

Drag may be expressed either in terms of a lift to drag ratio or as a coefficient. Although not all of the drag coefficients are available for the experimental curves tabulated in this study, as many as possible have been plotted versus the velocity ratios. They are designated by the same capital letters as their matching C_L curves (E,F,G,H,I,L).

Inspection of the C_D curves quickly reveals that the high aspect ratio cylinders have more favorable drag characteristics than do those of ratios of 6 to 1 or less. These plots also show a typical drop in drag of a rotor near the velocity ratio of 1.

The drag of a rotor can be computed by the equation:

$$D = \frac{C_D A \rho V^2}{2} \qquad \text{(equation 6.6)}$$

which is derived from the relationship:

$$C_D = \frac{D}{\frac{1}{2}\rho A V^2}$$ by solving for D (Ref. 28).

EXAMPLE:

Calculate the drag of the rotary rudder described in the previous example.

C_D = 3.05 at v/V = 3 (from curve "I")

$$D = \frac{3.05 \times 9 \times 1.94 \times 182.36}{2} = 4855.6 \text{ lbs}$$

Once the lift and drag forces acting upon a rotor have been computed the only remaining unknown factor is the power needed to overcome surface friction to spin it at the desired rpm. To do this we must first learn the torque. The Reynold's number approach is usually used by scientific investigators.

The Reynold's number for a cylinder is

$$R_N = \frac{\rho V d}{\mu} \qquad \text{(equation 6.7)}$$

diameter = 1.5' = d
radius = 0.75' = r
surface velocity = 3 x 13.5 ft/sec = 40.5 ft/sec
diameter of end plates = 3.0'

First determine the surface area and effective radius of the rotor elements.

SURFACE	AREA	EFFECTIVE RADIUS
A - cylinder	28.27 sq. ft.	0.75 ft.
B - outer plate (2)	7.07 sq. ft.	1.00 ft.
C - inner plate (2)	5.30 sq. ft.	1.25 ft.

The effective radius of the outer surfaces of the end plates (circles) is taken as 2/3 x radius. The effective radius of the inner surface of the end plates is taken as (2/3 x plate radius minus cylinder radius)plus cylinder radius.

Using equation 6.9, the torque required for the cylinder only is:

$$T_A = 0.01 \times 28.27 \text{ sq. ft.} \times 40.5^{1.825} \times 0.75 \text{ ft.}$$
$$T_A = 181.97 \text{ lb. ft.}$$

The velocity at the effective radius of surface B is:

$$v_B = \frac{r_A}{r_B} \times v = \frac{1.00 \text{ ft.}}{0.75 \text{ ft.}} \times 40.5 \text{ ft./sec.} = 54 \text{ ft./sec.}$$

The torque for the two surfaces B is:

$$T_B = 2 \times 0.01 \times 7.07 \text{ sq. ft.} \times 54^{1.825} \times 1.00 \text{ ft.}$$

$$T_B = 205.15 \text{ lb. ft.}$$

The velocity at the effective radius of surface C is:

$$v_C = \frac{1.25 \text{ ft.}}{0.75 \text{ ft.}} \times 40.5 \text{ ft./sec.} = 67.5 \text{ ft./sec.}$$

The torque for the two surfaces C is:

$$T_C = 2 \times 0.01 \times 5.30 \text{ sq. ft.} \times 6.75^{1.825} \times 1.25 \text{ ft.}$$
$$T_C = 288.87 \text{ lb. ft.}$$

The total torque needed for the rotor is:

$$T = 181.97 + 205.15 + 288.87$$
$$T \doteq 675.99 \text{ ft. lb.}$$

The rpm is found by using:

$$\text{rpm} = \frac{60v}{2\pi r} \qquad \text{(equation 6.10)}$$

$$\text{rpm} = \frac{60 \times 40.5 \text{ ft./sec.}}{2\pi \times 0.75} = 514.68 \text{ rpm}$$

Where

d = diameter of the cylinder

and

μ = coefficient of dynamic viscosity

The required torque would be

$T = C\rho n^2 l d^4$ (equation 6.8) (Ref. 29)

Where

C = a torque coefficient, function of Reynolds number
n = rpm of rotor
l = length of rotor
d = diameter of rotor

Some values for C are:

R_N	0.5×10^5	1.0×10^5	1.3×10^5
C	0.065	0.050	0.045

Obviously the Reynolds number method of determining rotor torque is rather ponderous and an accurate coefficient of dynamic viscosity is hard to pin down in the marine environment. Historically this method has resulted in undersized rotor drive systems.

A simpler and more conservative formula is derived from Froude (Ref. 30). The cylinder torque:

$T = fSv^{1.825}r$ (equation 6.9)

Where

f = a friction factor
f (water = 0.01
f (air) = 0.0000121
S = surface area of cylinder or end plates
v = surface velocity in feet per second
r = effective radius

EXAMPLE:

Compute the torque, rpm and horsepower for the rotary rudder used in previous examples.

Given

length = 6.0' = 1

To find the horsepower required to spin the rotor at 514.68 rpm, use the formula:

$$hp = \frac{\text{torque x rpm}}{5252} \qquad \text{(equation 6.11)}$$

$$hp = \frac{675.99 \times 514.68}{5252} = 66.24 \text{ hp}$$

It is easy to see from the foregoing torque computations that large end plates attached to the cylinder absorb a great amount of power that does not contribute directly to the Magnus effect.

For over a half a century theorists have strived to produce a general equation to account for Magnus effect behavior. Inspection of the C_L and C_D curves with their great diversity indicates what a difficult project it is. The Kutta-Joukowski equation (6.1) is useful in illustrating how lift is generated by rotating bodies, but it is not very helpful to the engineer who is designing a Magnus effect system. The procedures explained in this chapter are to be used for preliminary design guidance only. Until a sufficient number of full-sized applications have been made to provide feedback confirmation, scale model tests should be conducted prior to any prototype construction.

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CHAPTER 7

A COMPARISON OF MAGNUS EFFECT WITH STATE-OF-THE-ART DEVICES

It is anticipated that Magnus effect applications installed in lieu of conventional devices will generally yield higher performance per dollar cost. Among the reasons to expect this is simplicity. Rotating cylinders are mechanically simple and structurally inexpensive. No exotic materials or high technology engineering are needed, retrofits can be worked out by ordinary designers and draftsmen. Another reason to expect savings is that Magnus effect systems are fuel and manpower cost effective. This is particularly true of rotorsails as compared with other wind propulsion methods. Further benefits are to be realized by increased safety at sea.

SAILS

The logical point to begin comparisons between rotors and conventional systems is wind propulsion since it is the earliest and best known application. It would be unfair to match a rotor sail against an antique rig of the early 1900's ; it should be compared with an example such as the Dynaship rig that was developed with present day technological skills at the Institute of Shipbuilding in Hamburg. A considerable increase in lift was achieved by using high aspect ratio sail-wings having a constant curvature. There are no gaps between the lower leeches and the yards. Standing rigging and external running gear are absent, the latter is located within the spars.

The Dynaship rig exhibits its highest C_L of 1.5 with the apparent wind at 60° off the bow. C_D at the same heading is 1.15 so L/D is 1.3.

Now, for the sake of comparison, let us consider a rotor sail having the following characteristics:

Height	60 ft.	
Diameter	10 ft.	
Projected area	600 sq. ft.	
Endplate diameter	16 ft.	
Rotating at	206.3 rpm	
Peripheral velocity	108 ft./sec.	
C_L at v/V = 4	10.8	
C_D at v/V = 4	7.7	(curve E & Figures 24 & 25)
$L/D = C_L/C_D =$	1.4	(Figure 26)

Both ships operating in the following conditions:

Velocity, apparent wind	16 knots or 27 ft./sec.
Wind direction	60° off bow

Total thrust of the rotorsail is represented by the equation:

$$F = \frac{C_L A \rho V^2}{2} \cos 30° - \frac{C_D A \rho V^2}{2} \sin 30°$$

$$F = \frac{10.8 \times 600 \times 0.0023 \times 729}{2} \times 0.866$$
$$- \frac{7.7 \times 600 \times 0.0023 \times 729}{2} \times 0.5$$

$$F = 4704.55 \text{ lbs.} - 1936.59 \text{ lbs.} = 2767.96 \text{ lbs.}$$

The area of a DynaShip rig sail ($C_L = 1.5$ and $C_D = 1.15$) developing thrust in the direction of motion equal to the rotorsail in the same wind velocity from the same heading would have to be:

$$A = \frac{2F}{\rho V^2 (C_L \cos 30° - C_D \sin 30°)}$$

$$A = \frac{2 \times 2767.96}{0.0023 \times 729\ (1.5 \times 0.866 - 1.15 \times 0.5)}$$

$$A = 4560.44 \text{ sq. ft.}$$

which is 7.6 times larger than the rotorsail, clearly demonstrating the virtue of compactness of the cylindrical sail configuration.

From the standpoint of transverse stability the superiority of the rotorsail is obvious. Assuming that the distance from the waterline to the base of the sail is 20 feet in both instances, the heeling lever arm for the rotorsail would be:

$$20 \text{ ft} + \frac{60 \text{ ft.}}{2} = 50 \text{ ft.}$$

The dimension of the Dynaship rig would be 151 by 30.2 ft. with an aspect ratio of 5. Its centroid is:

$$\frac{151 \text{ ft.}}{2} + 20 \text{ ft.} = 95.5 \text{ ft. above the waterline.}$$

With the wind directly abeam the heeling moment for the rotorsail is:

$$M_H = \text{vertical lever} \times \frac{C_D A \rho V^2}{2}$$

$$M_H = 50 \times \frac{7.7 \times 600 \times 0.0023 \times 729}{2} = 193{,}659 \text{ ft. lbs.}$$

and for the Dynaship rig:

$$M = 95.5 \times \frac{1.25 \times 4560 \times 0.0023 \times 729}{2} = 456{,}356 \text{ ft. lbs.}$$

about 2.4 times greater. The rotorsail is better from the standpoint of stability than a Dynaship rig of equal thrust.

PROPELLERS

Moving on to the second mode of Magnus effect propulsion, propellers, the comparision with conventional types must contain more of an element of conjecture. Working models have demonstrated that cylindrical propeller blades produce thrust, but no full sized prototypes have yet been tested at sea.

In the next example a 9 foot diameter, 3 bladed, nozzled (Borg type) rotor propeller will be analyzed with respect to its thrust (bollard pull) and the shaft horsepower needed to turn it and spin its rotors. It has the following characteristics:

Shaft speed	100 rpm	
Rotor diameter	1 ft.	
Rotor length	4 ft.	
Hub diameter	1 ft.	
V at rotor tip	47.1 ft./sec.	
V at hub	5.23 ft./sec.	
Rotor speed	900 rpm	
v/V at tip	1	
C_L at tip	1.15	
C_D at tip	0.55	(curve L, Figures 23 & 25)
v/V at hub	9	
C_L at hub	10.2	
C_D at hub	1.75	(curve L, Figures 23 & 25)
ρ sea water	1.99	

The hub and nozzle serve as end plates so the coefficients are represented by Swanson's rotor of infinite length.

$$\text{Total lift per rotor } L = \frac{L \text{ at tip} + L \text{ at hub}}{2} \times \text{rotor length}$$

$$\text{using } L = \frac{C_L A \rho V^2}{2} \qquad \text{(equation 6.5)}$$

$$L \text{ total} = \frac{\left(\frac{1.15 \times 4 \times 1.99 \times 47.1}{2}\right) + \left(\frac{10.2 \times 4 \times 1.99 \times 5.23}{2}\right)}{2} \times 4 \text{ ft.}$$

$$L \text{ total} = (10153.66 + 1104.42 \times 2 = 22{,}528.16 \text{ lbs}$$

Similarly total drag per rotor: $D = \frac{\text{D at tip} + \text{D at hub}}{2} \times \text{rotor length}$

Using $D = \frac{C_D A \rho V^2}{2}$ (equation 6.6)

$$D \text{ total} = \frac{\left(\frac{0.55 \times 4 \times 1.99 \times 47.1}{2}\right) + \left(\frac{1.75 \times 4 \times 1.99 \times 5.23}{2}\right)}{2} \times 4 \text{ ft.}$$

D total = (4856.10 + 190.51) x 2 = 10093.23 lbs.

torque = Drag x lever = 10093.23 x 2.5' = 25233.08 lb. ft.

Horsepower to turn $= \frac{\text{torque} \times \text{rpm}}{5252} = \frac{25233.08 \times 100}{5252} = 480.4$ hp

torque to spin rotor $= fSv^{1.825} = 0.01 \times 12.57 \times 47.1^{1.825}$

T = 142.1 lb. ft.

Horsepower to spin rotor $= \frac{142.1 \times 900}{5252} = 24.4$ hp

total horsepower for 3 rotor prop = 3 x (480.4 + 24.4) = 1514.4 hp

total thrust for 3 rotor prop = 3 x 22528.16 = 67584.5 lbs.

Thrust per shaft hp $= \frac{67584.5 \text{ lbs.}}{1514.4 \text{ hp}} = 44.63$ lbs./hp

This ratio represents a 78.5% improvement over conventional open wheels that can be expected to deliver about 25 lbs. of thrust per horsepower (Ref. 31). It is a 55.2% increase in efficiency over a nozzled prop developing 28.75 lbs. per horsepower (Ref. 28).

A decrease in appendage drag due to the smaller area of the rotors will further benefit a vessel's performance while underway. The complexity of a Magnus effect propeller is no greater than that of a controllable pitch propeller so cost is expected to be comparable.

RUDDERS

The third comparision concerns Magnus effect versus conventional steering. Here the emphasis is upon improved low speed maneuverability; no attempt is made to, let us say, double the turning force at full speed ahead. To do so would require major structural changes in the stern of a retrofit vessel and might even cause stability problems. An oversized rotary rudder could conceivably put a vessel's deck edge underwater while executing a sharp maneuver at full speed.

In the next example a conventional semi-balanced rudder will be analyzed then matched with a Magnus effect rudder having about the same high speed capability but with greatly improved low speed performance. The example rudder dimensions are:

Height	9 ft.
Length	4.5 ft.
Hard over angle	35 degrees
Maximum wake velocity	14 knots or 23.6 ft./sec.

The total force acting upon the rudder at full speed, hard over is:

$$F = \frac{cA\rho V^2}{2}$$

Where

$$c = \frac{0.811 \sin 35°}{0.195 + 0.305 \sin 35°}$$

$$c = \frac{0.4652}{0.3699} = 1.2576$$

$$A = 9 \text{ ft.} \times 4.5 \text{ ft.} = 40 \text{ sq. ft.}$$

$$F = \frac{1.2576 \times 40.5 \times 1.99 \times 23.6^2}{2} = 28225.7 \text{ lbs.}$$

The maneuvering force component F acting perpendicularly to the direction of motion of the vessel is:

$$F_M = F \cos 35° = 23122.5 \text{ lbs.}$$

The drag caused by the hard over rudder, D, is:

$$D = F \sin 35° = 16190.3 \text{ lbs.}$$

Comparing the conventional rudder with a Magnus effect rudder 9 feet long and 1.5 feet in diameter turning at 300 rpm at V = 23.6 ft./sec. and v/V = 1.0, $C_L = 3.1$ and $C_D = 0.5$

$$L = \frac{C_L A\rho V^2}{2} \text{ and } D = \frac{C_D A\rho V^2}{2}$$

$$\text{Maneuvering force} = L = \frac{3.1 \times 13.5 \times 1.99 \times 23.6^2}{2} = 23{,}192 \text{ lbs.}$$

or about equal to the conventional rudder.

$$\text{Drag} = D = \frac{0.5 \times 13.5 \times 1.99 \times 23.6^2}{2} = 3740.7 \text{ lbs.}$$

The difference in drag of the two rudders is 12449.6 lbs. The power wasted by the conventional rudder is noticed as lost headway during a turn but it also represents unnecessary fuel consumption.

Now let us compare the two steering systems at low speed, say a wake velocity of 3.5 knots or 5.908 ft./sec. First analyzing the same conventional rudder at 35 degrees.

$$F_M = \frac{CA\rho V^2}{2} \cos 35° \text{ and } D = \frac{CA\rho V^2}{2} \sin 35°$$

$$F_M = \frac{1.2576 \times 40.5 \times 1.99 \times 5.908^2}{2} \times .8192$$

$$F_M = 1768.89 \times 0.8192 = 1449 \text{ lbs.}$$

$$D = 1768.89 \times 0.5736 = 1014.6 \text{ lbs.}$$

and for the Magnus effect rudder at 300 rpm:

$$v/V = 4, \quad C_L = 11, \quad C_D = 7.3$$

$$L = \frac{11 \times 13.5 \times 1.99 \times 5.908^2}{2} = 5157.4 \text{ lbs.}$$

a steering force 3.6 times greater than that of the airfoil shaped rudder.

$$D = \frac{7.3 \times 13.5 \times 1.99 \times 5908^2}{2} = 3422.6 \text{ lbs.}$$

The Magnus effect system carries a drag penalty at very low speeds.

For purposes of illustration the rotor versus conventional rudder comparison was made with the rotor spinning at its maximum rpm and the conventional rudder hard over. This situation would be normal for towboats working on the inland waterways but would not necessarily be true for vessels maneuvering in larger bodies of water. Lesser rudder angles naturally produce smaller drag components but since the drag developed by a rotor is largely due to a mass of entrained water surrounding it, lower rpm means less drag for the cylindrical rudder also. The virtue of Magnus effect steering is that at maximum speed it can produce the same turning force as a conventional rudder but with much less drag while at very low speeds it can develop more than three times the turning force. The rotor's low speed drag penalty is far outweighed by the improved maneuverability.

STABILIZERS

The computations involved in comparing fin type and Magnus effect stabilizers are identical to those used for rudders in the previous example. Stabilizers should be sized so the v/V = 1 at top speed to take advantage of the low C_D at that ratio. The retractable feature of rotor stabilizers eliminates the need for an end plate on the inboard end of the cylinder; the surface of the hull serves as a pressure field.

The power required by a rotor stabilizer of the same dimensions as the rotor in the previous comparison (9' x 1.5" x 300 rpm) and having a single end plate 3 feet in diameter would be computed as follows:

SURFACE	AREA	EFFECTIVE RADIUS	V AT E.R.
A - Cylinder	42.41 sq ft	0.75 ft	23.60 ft/sec
B - Outer plate (1)	7.07 sq ft	1.00 ft	31.47 ft/sec
C - Inner plate (1)	5.30 sq ft	1.25 ft	39.33 ft/sec

torque $T = fSv^{1.825}r$ (equation 6.9)

$$T_A = 0.01 \times 42.41 \times 320.31 \times 0.75 = 101.88 \text{ lb. ft.}$$
$$T_B = 0.01 \times 7.07 \times 541.58 \times 1.00 = 38.29 \text{ lb. ft.}$$
$$T_C = 0.01 \times 5.30 \times 813.53 \times 1.25 = 53.90 \text{ lb. ft.}$$

$$T = T_A + T_B + T_C = 194.07 \text{ lb. ft.}$$

$$hp = \frac{194.07 \times 300}{5252} \times 2 = 22.17 \text{ hp}$$

The total horsepower required to operate a pair of Magnus effect stabilizers capable of imparting a total force of 46,384 lbs. at a speed of 14 knots is 22.17 horsepower. The low power requirement coupled with its simplicity and full retractability makes the rotor stabilizers a strong competitor with fin type stabilizers.

SUMMARY

In the paper "Revival of the Flettner Rotor - Beneficial or Not for Merchant Vessels, Fishing Boats and Recreational Craft?" (Ref. 19) presented in November of 1983 at the Annual Meeting of the S.N.A.M.E., the Swedish naval architects Williams and Liljenberg analyze the coastal vessel "Stellan". The decrease in fuel consumption using rotorsails as auxiliary power is estimated at 17.5%, a savings of $12,100 based on 190 days at sea per annum and a fuel price of $205 per ton. If its conventional propeller was replaced by a Magnus effect unit, increasing propulsive efficiency by an additional 25%, another $14,260 would be saved. The Stellan can be steered by a computer controlling the rpm of the rotorsails so the addition of Magnus effect steering underwater would not directly benefit fuel consumption. The same is true for rotary stabilizers in this case, thus the Stellan could realize a total reduction in fuel consumption of 42.5%. This is an improvement in performance of an astonishing magnitude when one considers that naval architects are quite pleased to achieve gains in performance of 2 or 3 percent.

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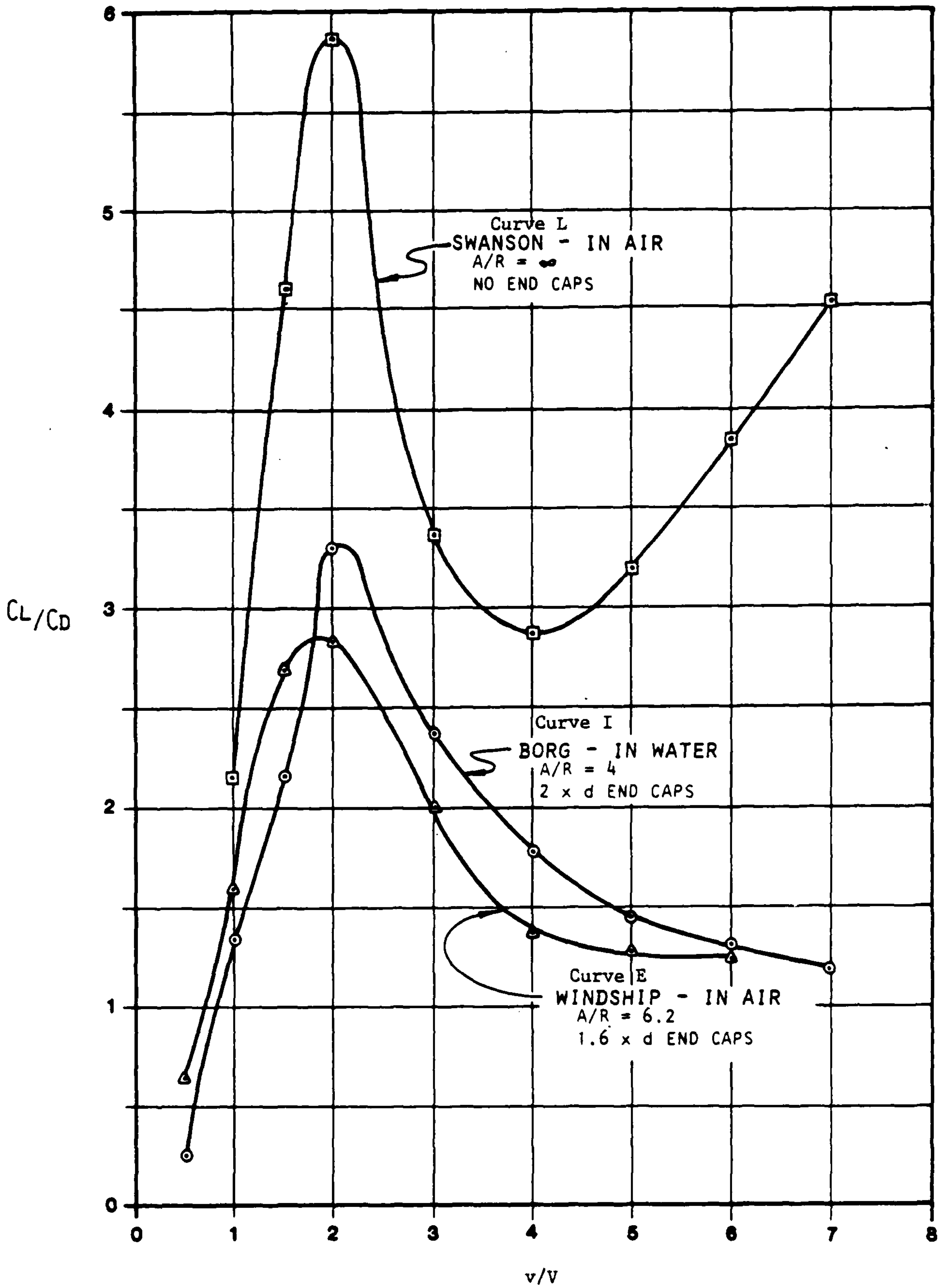


ROTOR LIFT/DRAG CURVES

FIGURE 26

CHAPTER 8

IDENTIFY FURTHER TESTING REQUIRED TO FULLY EVALUATE THE POTENTIAL FOR MAGNUS EFFECT PROPULSION, STEERING, STABILIZERS AND ENERGY CONVERTERS

At the present time a mathematical model that adequately expresses Magnus effect forces for a variety of rotor configurations is not available to engineers and naval architects. Experimental data must be relied upon to select rotor geometry and velocity relationships when designing new applications. Although the family of C_L and C_D curves, generated by experimenters over the past half century falls into a reasonable envelope, it exhibits differences that could be the result of older measurement techniques. Supersensitive electronic measuring devices and computer systems are now available to reduce the possibility of observer errors.

The remainder of this chapter will be devoted to identifying aspects of the Magnus effect that have not been clarified by earlier experimentation. The intent of further testing is to refine the knowledge of the phenomenon into a form that can be readily be used by applications engineers when designing reliable rotor systems.

The influence of the types of fluids, extremes in mass-density and Reynolds number should be investigated first. For instance, is there a difference in Magnus effect behavior in a liquid, say water, and a gas, such as air? Does the compressibility of air result in different coefficient curves for rotors of identical geometry? Will performance remain predictable in a very light or very heavy density fluid such as air at high altitude or low temperature sea water? If the differences in fluid can be accounted for in the tests then further experiments may be conducted in whichever medium is convenient or appropriate.

It is desirable that as much testing as possible be carried out in water. There are several reasons for this choice. First, very few prior experiments were done in liquid, yet many attractive applications are for underwater devices. Using a towing basin for the work would bring out any still unknown anomalies. The density of a liquid is easier to record and control, the influence of humidity and/or small changes in atmospheric pressure upon viscosity would not be a problem as they would be when using a wind tunnel. Model velocity and rpm would be much lower in water and therefore the model itself would be less expensive. Wake behavior is observable in water and can be seen as a surface effect; no smoke devices, etc. are needed. Finally interface phenomena such as ventilation cannot be tested in an all enveloping gas medium.

To assemble the desired test data the following problems should be investigated.

TORQUE

One of the gray areas in Magnus effect application is the exact accounting of the torque required to spin a rotor assembly. The Reynolds number method generally results in undersized power units and the Froude approach tends to be too conservative. A range of surfaces from very smooth to sanded to bumpy must be tested to determine real friction factors. Observation should be made during this phase of the effect of texture on negative lift at low velocity ratios and its influence on lift and drag as well.

ASPECT RATIO

It is well known that aspect ratio is an important factor in Magnus effect efficiency but it has not been evaluated in a fashion that can be conveniently applied. Aspect ratio tests must be conducted in such a manner as to preclude the influence of end plate diameter upon lift.

END PLATES

The determination of optimum end disk diameter should be conducted after aspect ratio parameters are known. The impact of less than optimum diameter must be found, as well. During end plate experimentation the performance of fixed versus spinning types should be determined and the maximum allowable gap between fixed disk and cylinder end.

DRAG DISAPPEARANCE

It was pointed out in earlier chapters that the Barkley phenomenon of drag disappearance is important in fuel conservaton for rudders and stabilizers and "hurricane proofing" of rotor sails. Low velocity ratio runs for a number of rotors of different geometries and textures should be a part of the program in order to better understand this useful characteristic of the Magnus effect.

AUTOROTORS

Energy converters and possibly propellers could use autorotating blades. The relative merits of a number of autorotors with respect to lift, drag and selfstarting capability should be observed and measured.

VISIBLE FLOW PATTERNS

The technique of using smoke, dye or streamers to visually demonstrate flow patterns is of less interest to engineers than it would be to physicists and rates a low priority in the proposed Magnus effect test program.

PROPELLERS

The rotor bladed propeller concept is very attractive from the standpoint of increased thrust per horsepower. Feasibility tests using a simple Magnus effect propeller model to measure thrust in still and flowing fluid and to discover if circulation and interblade interference problems exist should be conducted.

YAW

Closely related to the propeller study is the effect of non-perpendicular flow or yaw upon a rotor. Lift measurements should be taken with a rotor canted at a series of angles with respect to the direction of flow.

INTER-ROTOR INFLUENCE

Problems are anticipated in the design of side-by-side rudders or sails. A pair of rotors should be used to determine minimum distances between twin rotors spinning at equal and also different surface velocities and directions. A clear understanding of inter-rotor influence is essential to multiple Magnus effect application development.

VELOCITY LIMITS

An important part of the experimental program is that of discovering if a surface velocity limit exists at which Magnus effect forces are altered or diminished. These might be akin to cavitation in conventional propellers and again may not be a problem at all. It is possible the bubbles may form on the surface of high speed rotors, it is not known if this would cause diminished lift due to loss of friction.

VENTILATION

Similarly the effect of ventilation should be investigated. This is very important in stabilizer design because of proximity to the surface. No present knowledge of rotor ventilation exists because most experiments have taken place in wind tunnels.

STEERING

Magnus effect steering systems have proven to be highly effective and, without a doubt, will become important in ship design. Tests should be made to find the optimum distance the rotor must be positioned from the propeller and from the hull. Information regarding the influence of the hull and appendages such as nozzles and struts are to be investigated.

RADAR SIGNATURE

Of particular interest for naval use is the radar signature of a rotor sail. If possible, full sized vessels should be used for radar signature studies.

OPTIMIZATION OF L/D

It appears from an examination of Figure 26 that for most rotors a v/V of 2.0 provides for maximum L/D ratios. However, at high v/V ratios with high aspect ratio cylinders, L/D shows an increasing trend which may result in higher L/D ratios than those found at v/V = 2.0. Experimentation with practical high aspect ratio rotors (i.e. 12d) should shed some light on the optimum L/D ratio.

There are many partially understood areas and some serious gaps in our knowledge of the Magnus effect. The experimentation called for in this chapter should be carried out before much of the proposed prototype development can take place in order to avoid costly design errors.

CHAPTER 9

DEVELOP PLANS FOR FURTHER TESTS

I. GENERAL REQUIREMENTS OF MAGNUS EFFECT TESTS

A. Model Geometry

It is recommended that for all experiments not involving aspect ratio or end disk diameter study a "standard rotor" be used. The proportions of this rotor shall be: length = 6 x cylinder diameter and end plate diameter = 2 x cylinder diameter. The standard rotor shall be the first configuration tested in each fluid medium in order to establish base curves of coefficients of lift and drag and to define friction factors.

B. Model Size

It is desirable to use the largest sized possible rotors for the tests in order to avoid high rpm requirements and scale effects. Final decisions regarding the precise size of the models cannot be made until the test facilities have been selected. Factors such as the wind tunnel width and the depth of the towing basin will partly predicate the cylinder dimensions. It should also be borne in mind that Magnus effect forces are many times greater than conventional airfoils of similar size. This could lead to overstressing or damage to the test facilities fixtures and measuring devices.

C. Test Data to be Recorded

With the possible exception of propeller experiments, the following information is to be recorded for each test run:

1. free stream flow velocity,
2. rotor rpm and surface velocity,
3. rotor shaft torque,
4. lift,
5. drag,
6. wake deflection angle (water tests only).

In addition to the preceeding, the following informations regarding the fluid (or testing medium) is to be recorded for each day's test series:

1. density,
2. viscosity,
3. temperature,
4. atmospheric pressure and humidity (air tests only).

D. Data Presentation

The recorded data will, no doubt, be presented in computer print-out sheets. It is then to be reduced to a tabular form. A second set of tables is to be generated from the first which will be organized in order of increasing velocity ratios and will show the following information:

1. mass density (ρ) in slugs/ft ,
2. Reynolds number,
3. coefficient of lift,
4. coefficient of drag,
5. lift to drag ratio,
6. rotor shaft horsepower.

The data from the refined tables is to be plotted as a group of curves for each test series. The following values are to be represented graphically.

1. C_L versus v/V,
2. C_D versus v/V,
3. lift versus drag,
4. horsepower versus rotor rpm.

E. Selection of Fluid Medium for Tests

If it can be shown that no unaccounted for differences exist between Magnus effect phenomena in air and in water, then redundant testing in both media is eliminated. As an example, the information gained from twin rudder tests will be applicable to multiple rotorsail arrangements and thus need not be repeated in a wind tunnel. It is preferable that the majority of the experimentation be carried out in water, for the reasons given in Chapter 8.

F. Experimental Priorities

The following list indicates the importance of wind tunnel tests with the highest priority first:

1. standard rotor test, (Figure 27)

2. standard rotor test with 2 other textures,
3. standard rotor high surface velocity test,
4. standard rotor low density medium test,
5. standard rotor, photograph visual flow patterns.

This second list indicates the relative importance of experiments to be conducted in water with the highest priority first:

1. standard rotor test,
   (if correlation is found with air test of standard rotor, no further wind tunnel work is necessary), (Figure 27)
2. standard rotor test with 2 other textures,
3. aspect ratio tests,
4. end plate tests of various diameters attached to rotor, free spinning and fixed,
5. rotary rudder with propeller and hull tests, (Figure 28)
6. dual rotor interference experiments, (Figure 29)
7. rotor yaw tests, (Figure 30)
8. ventilation experiment, (Figure 30)
9. Magnus propeller feasibility test, (Figure 31)
10. autorotor evaluations, (Figure 32)
11. high density fluid test,
12. high surface velocity test.

II. WIND TUNNEL TEST DETAILS

After a wind tunnel test facility has been decided upon and the appropriate size of the standard rotor has been selected, experiments are to proceed in accordance with the priority guidelines indicated in subparagraph "F".

It is important that the first two tests (1. standard rotor and 2. standard rotor with 2 other textures) have priority as they are necessary for comparison with the water tests. The remaining three wind tunnel tests are elective.

Data is to be recorded and presented as outlined in subparagraphs "C" and "D".

III. TOWING BASIN TEST DETAILS

When the dimensions of the underwater standard rotor have been chosen in view of the conditions enumerated in subparagraph "B", experimentation is to be in order of the priorities listed in subparagraph "F".

Data is to be recorded and presented as previously described.

IV. RUDDER LOCATION TEST DETAILS

The purpose of this experiment is to determine the ideal distance that a rotary rudder should be positioned behind a conventional propeller for maximum efficiency of the combination.

The two values to be measured are the effect upon propeller thrust (bollard pull) and the change in transverse lift (manuevering force) caused by varying the distance between the two elements. At the same time, hull and appendage interference can be studied. This investigation could become very elaborate, expensive and time consuming therefore it is important to impose strict limitations on its scope and to restrict the test aparatus to the most simple and practical arrangement. The effects of flow caused by a vessel's forward motion need not be considered in the rudder location test and it is to be carried out in a fixed location in the tank.

The suggested model arrangement could consist of a simple scow-like float representing the underside of a hull, it may have a flat bottom and vertical sides and ends. This float is to be connected to measuring devices capable of recording fore and aft thrust and transverse lift. A well located on the centerline will be used to house the rotary rudder and alternately, a flow velocity measuring device (log). The rotor is to be driven by a variable speed electric motor, reversibility is not required. The rotor and velocity log may be raised or lowered with respect to the underside of the hull by means of adjustable brackets. A second well or slot is to extend forward of the rotor well for a distance of from one-half to 4 times the propeller diameter, again adjustable brackets will allow the propeller to be moved fore and aft and raised or lowered as desired. In order to avoid the expense of constructing a special propeller and drive unit, it is suggested that the lower assembly of a small horsepower, low rpm outboard motor such as a "Seagull" be adapted to be driven by a reversible electric motor of suitable power through an appropriate belt or gear reduction arrangement. Finally, a simulated appendage or strut is to be fashioned in a manner that will allow it to be positioned as desired with C-clamps near the rotor.

The main portion of the experiment consists of a series of five tests with the propulsion unit located at one-half, 1, 2, 3 and 4 propeller diameters distant from the rotary rudder. Each test will be in both the forward and astern modes at a consistant propeller and rotor rpm. Flow and rotor surface velocities as well as thrust and lift are to be recorded at each stage. From this data, superimposed lift and thrust curves are to be drawn to enable the investigators to select an optimum rotor-propeller spacing expressed in terms of propeller diameter.

The second portion of the rudder location experiment is to be conducted at the selected rotor position. The information as called for in the earlier test is to be recorded with the propulsion and steering units lowered to various distances beneath the "hull". Finally the simulated appendage strut is to be clamped in several locations adjacent to the rudder and observations made as to its effect upon the maneuvering force.

It will not be necessary to reverse the direction of rotor rotation for this series of tests.

V. MAGNUS EFFECT PROPELLER EXPERIMENT DETAILS

The intent of this experiment is to determine the feasibility of a Magnus effect propeller operating in water. The most important knowledge to be gained will be the influence of flow caused by the forward motion of a ship upon the lifting force of the rotary blades. Secondly the relationship of the rotor surface velocity to the propeller's rotational speed must be investigated.

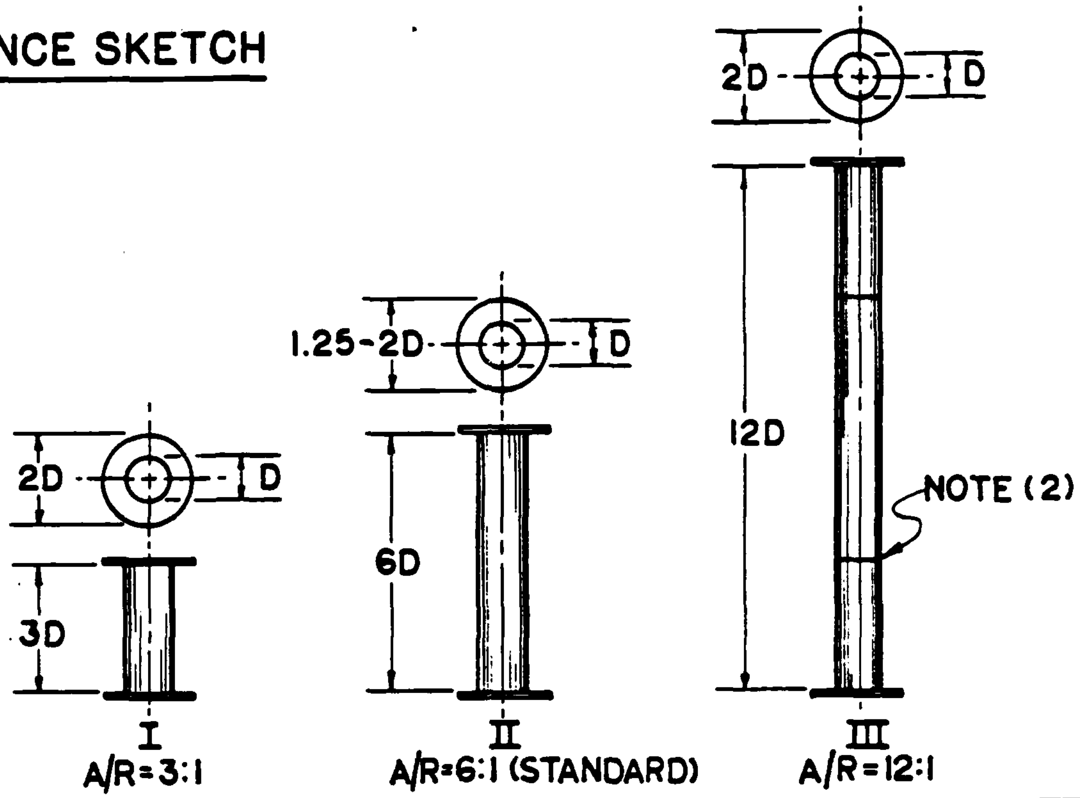
The apparatus for this experiment will consist of a propeller small enough to be used in a flow tank or basin. It is to have motor driven blades and it is desirable to be able to monitor the rotor blade rpm. The propeller shaft rotation will be provided by an additional motor whose torque and rpm can also be measured. The thrust output of the propeller assembly is to be measured during both static and underway trials.

During the first stage of the test a desirable rotor shaft to propeller shaft rpm ratio is to be established. Then the model is to be introduced into a flow of increasing velocity and the changes in thrust will be measured. A preliminary estimate of the feasibility of a Magnus effect propeller is to be made based upon the results of this experiment.

VI. GUIDANCE SKETCHES

Drawings are provided herein illustrating the suggested model and aparatus configurations for the rudder location and the propeller experiments as well as for the other tests called for in subparagraph "F".

GUIDANCE SKETCH



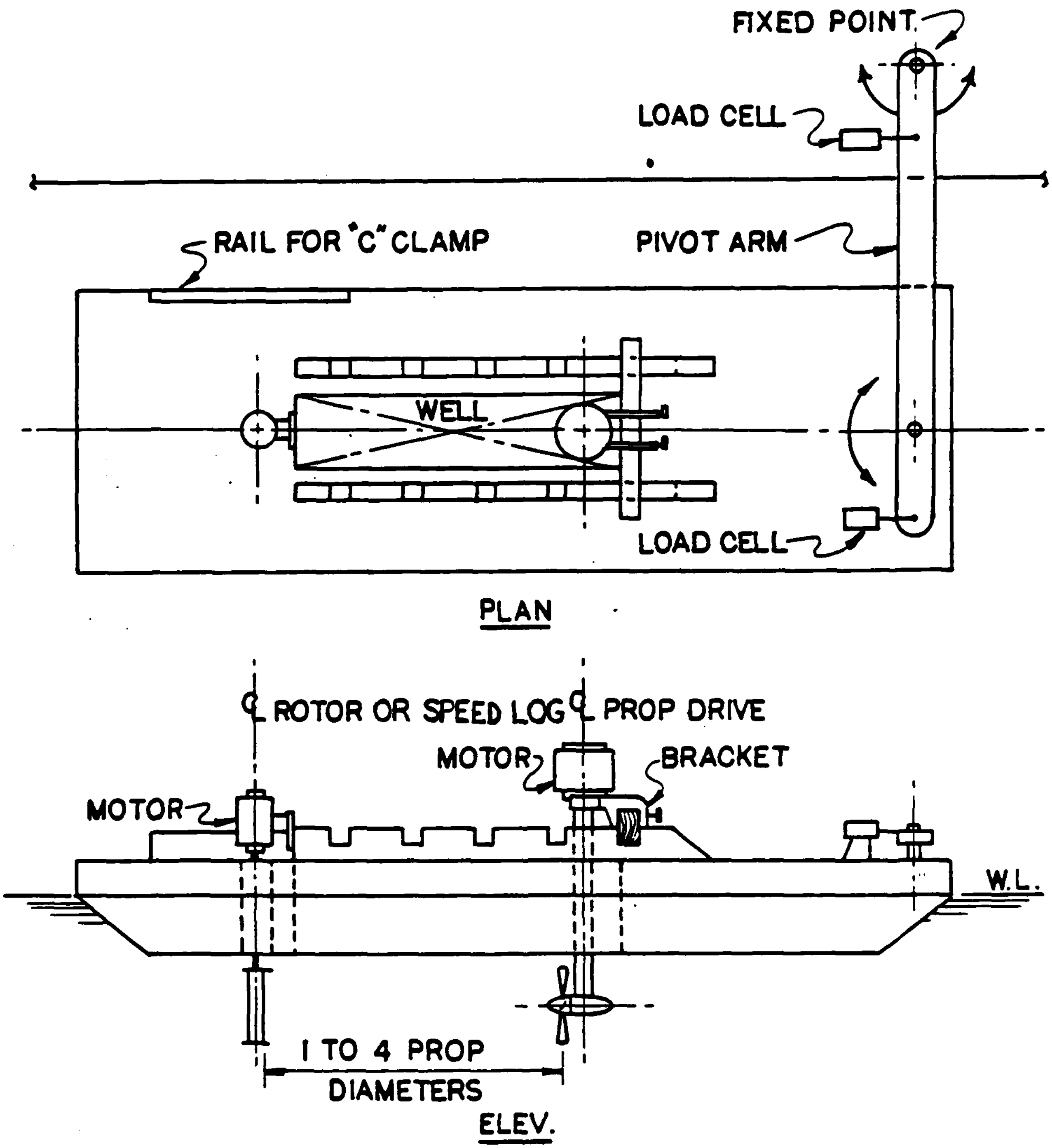
LENGTH OF CYL.	3 X CYL. DIA.	6 X CYL. DIA.	12 X CYL. DIA.
QUANTITY	2 EACH	3 EACH	1 EACH
SURF. TEXTURE	100 R.M.S.	100, 250 & 500 R.M.S.	100 R.M.S.
END PLATE DIA. (SEE NOTE (1))	2 X CYL. DIA.	1.25, 1.50, 1.75 & 2 X CYL. DIA.	2 X CYL. DIA.
END PLATE CONDITION	FIXED TO CYL.	ALL DIA. & TEXTURE VARIATIONS FIXED TO CYL. -ALSO- STD. TEXT. & E.P. DIA. FIXED TO TEST JIG & FREE SPINNING	FIXED TO CYL.

NOTES: (1) ALL END PLATES ARE TO HAVE A SURFACE FINISH OF 100 R.M.S. OR SMOOTHER.
(2) ROTOR III IS COMPOSED OF ROTORS I & II.

TEST ROTOR ASSEMBLIES

FIGURE 27

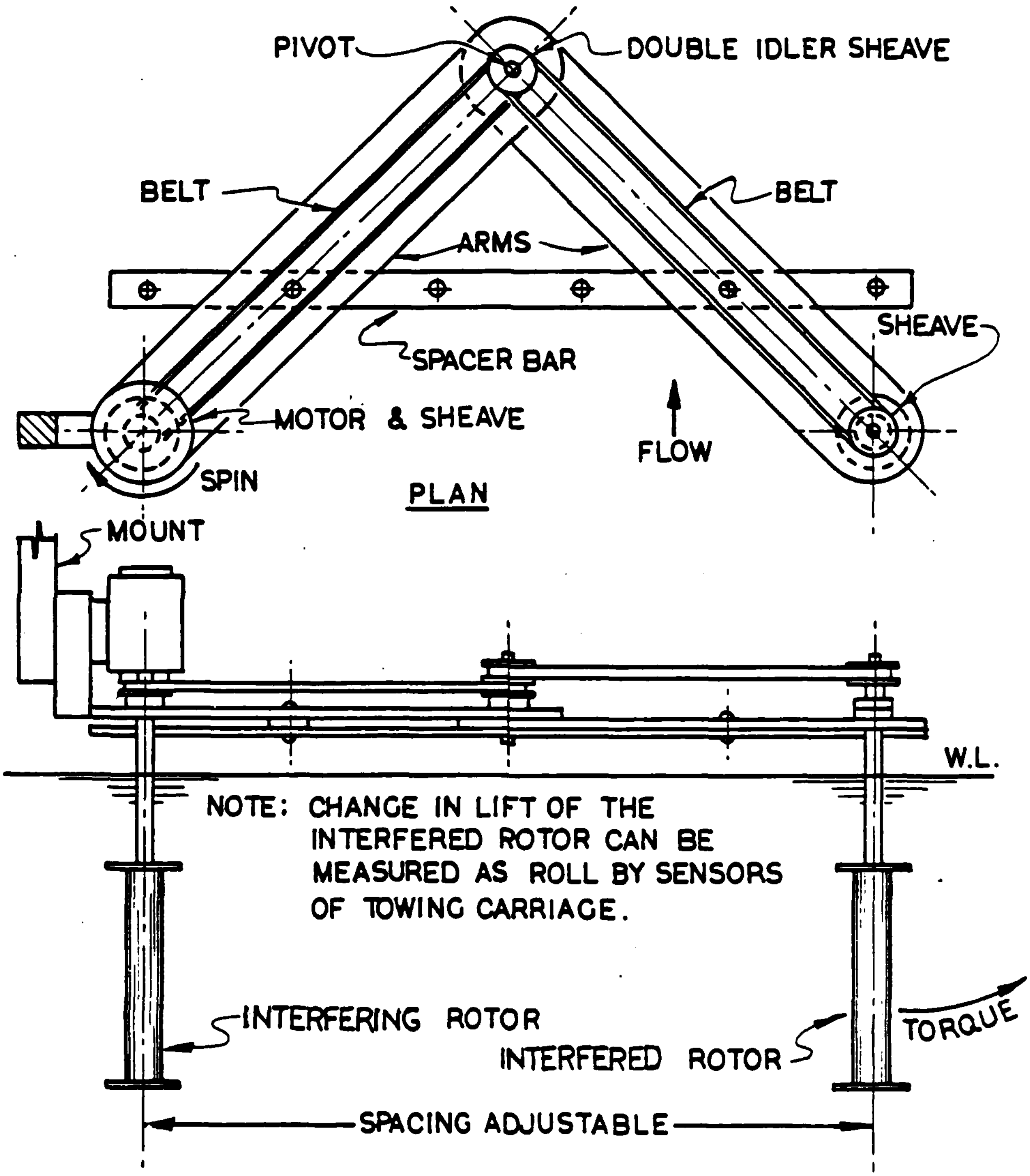
GUIDANCE SKETCH



RUDDER LOCATION TEST FIXTURE

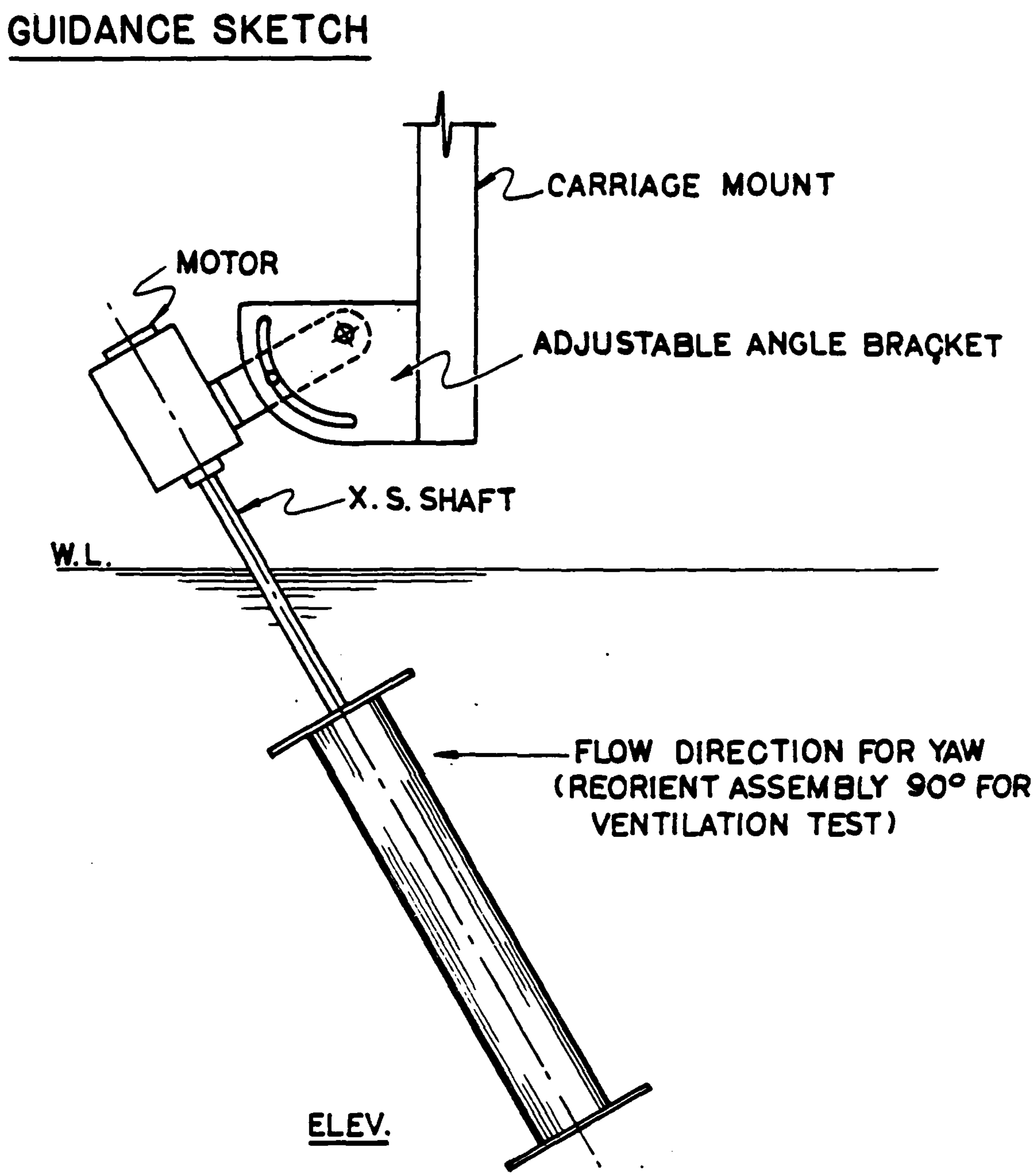
FIGURE 28

GUIDANCE SKETCH



DUAL ROTOR INTERFERENCE TEST

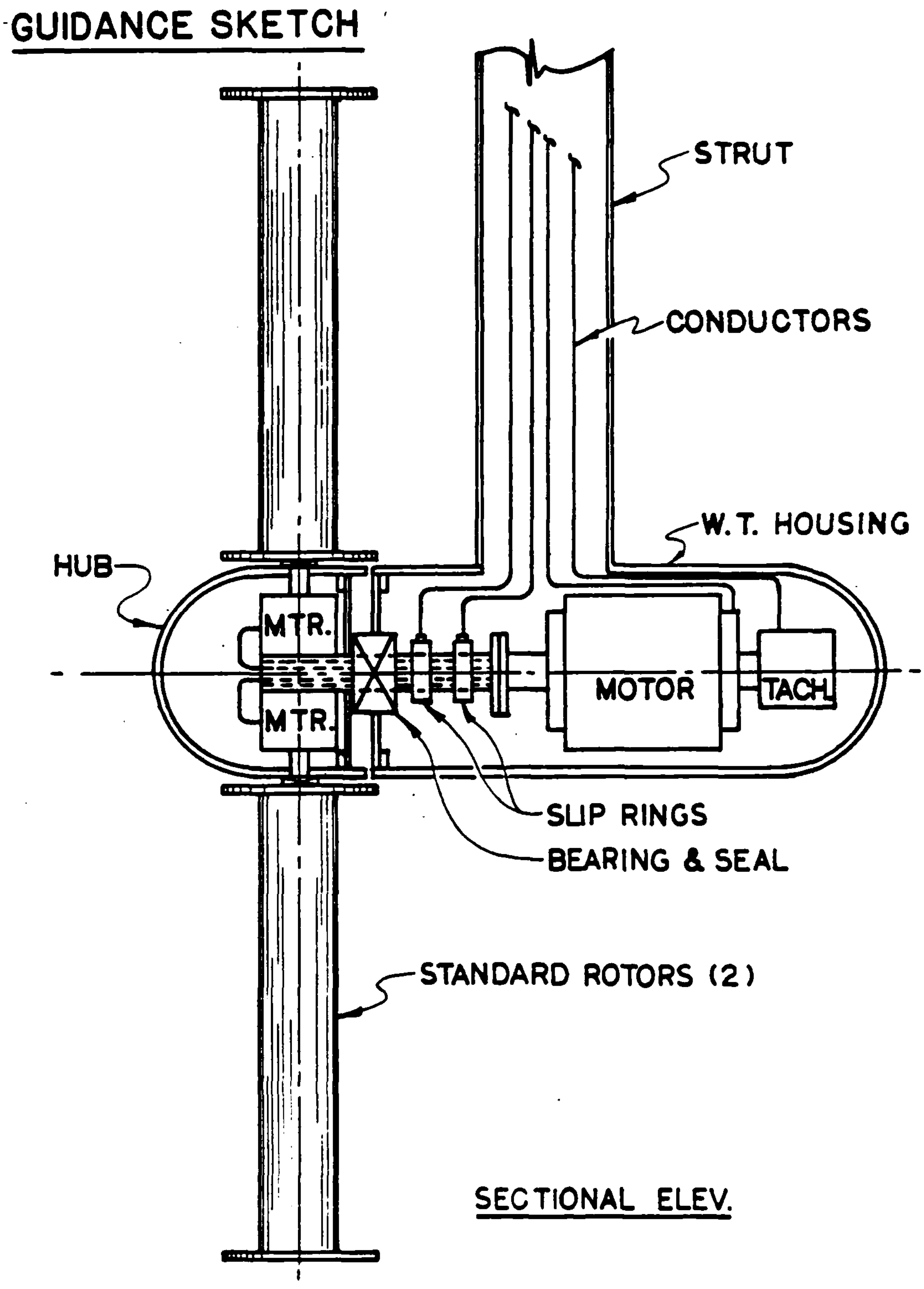
FIGURE 29



NOTE: TORQUE CAUSED BY CHANGE IN ROTOR LIFT AT VARIOUS ANGLES IS SENSED AS "PITCH" DURING YAW TESTS AND "ROLL" DURING VENTILATION TESTS.

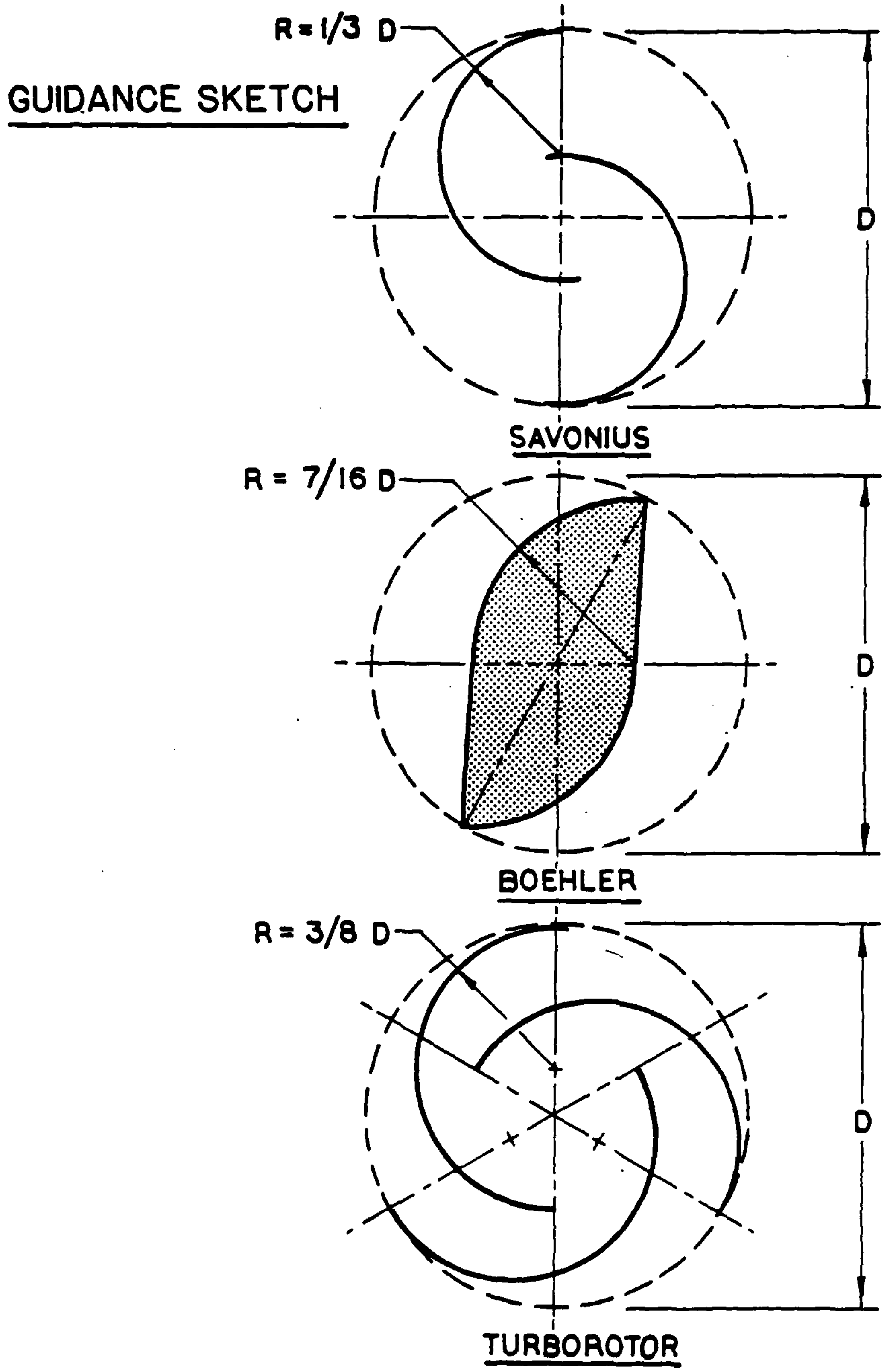
YAW AND VENTILATION TESTS

FIGURE 30



MAGNUS EFFECT PROPELLER

FIGURE 31



NOTE: AUTOROTOR MODELS ARE TO HAVE A LENGTH OF 6 X D AND END PLATES DIAMETER OF 2 X D.

MODEL AUTOROTOR PROPORTIONS

FIGURE 32

CHAPTER 10

SUMMARY

Since its discovery in the mid-nineteenth century, the Magnus effect has been the subject of many studies and experiments. The majority of this work was conducted in wind tunnels and the prinicipal areas of applicatons were for sails, windmills and aircraft. It is safe to say that sufficient data now exists to enable engineers to design practical and efficient rotor sails and wind energy converters and indeed, a number of working prototypes presently exist. With the possible exception of the Van Dusen sphere, Magnus effect flying machines have not yet evolved past the kite stage and it is difficult to predict if the use of the phenomenon in aviation will ever be of great significance.

Less progress has been made in the realm of underwater experimentation and application of rotary lifting surfaces. Attention has been focused primarily upon Magnus effect steering systems and tests conducted upon several vessels clearly indicate that cylindrical rudders are superior to conventional ones from many points of view. They are particularly good for ships that must maneuver frequently at low speeds such as tugs and towboats. The rotor is also less vulnerable to damage in debris or ice clogged waterways. Similarly, Magnus effect ship stabilizers can be expected to perform well. The technology required for both steering and stability systems is virtually identical. More testing is called for regarding the use of rotors beneath the water before they can expect widespread acceptance.

Magnus effect propellers have yet to be proven feasible. Although working models have been constructed and calculations indicate high thrust values, additional experimentation will be needed to demonstrate that they represent an improvement over the types of propellers presently in use.

It is difficult to pinpoint reasons for the slow development and acceptance of Magnus effect marine applicatons. Certainly a large number of patents exist encompassing the devices previously mentioned as well as those of interest to other industries. Normally the time lag between the introduction of an idea and its commonplace use is nothing like the 60 years it has taken Anton Flettner's invention to be regarded as a practical energy saving alternative. We can only assume that the abundance of cheap fossil fuel in the 1920's ended the brief flowering of the rotor ship. We know that the expensive fuel of the 1980's has brought it back into bloom.

It is reasonable to expect an upswing of interest in the Magnus effect from this time forward. An unprecedented number of articles on the subject have recently appeared in marine and scientific magazines to verify this. Increased funding for research and prototype development will doubtless follow.

The demand for cleaner energy sources is stimulated by such factors as pollution and the unknown consequences of the greenhouse effect. These and other contemporary influences will tend to bring the Magnus effect into everyday use. The time has come to resolve the remaining unknowns thus changing its status from a "phenomenon" into a useful technology.

Some convenient rules of thumb regarding the design of Magnus effect systems have come to light in the course of this study. They are:

1. the coefficient of lift increases with the aspect ratio,

2. the coefficient of lift also increases with end plate diameter,

3. a rotor with an aspect ratio of 6 provides a coefficient of lift greater that 10 yet is not so slender as to cause structural problems,

4. the practical range of end plate diameters is 1½ to 2 rotor diameters, and

5. excessively large end disks tend to require too much horsepower to overcome surface friction and should be avoided.

In conclusion it is hoped that the information furnished in this study will bring about more widespread use of Magnus effect devices by the Navy for greater efficiency and safety at sea.

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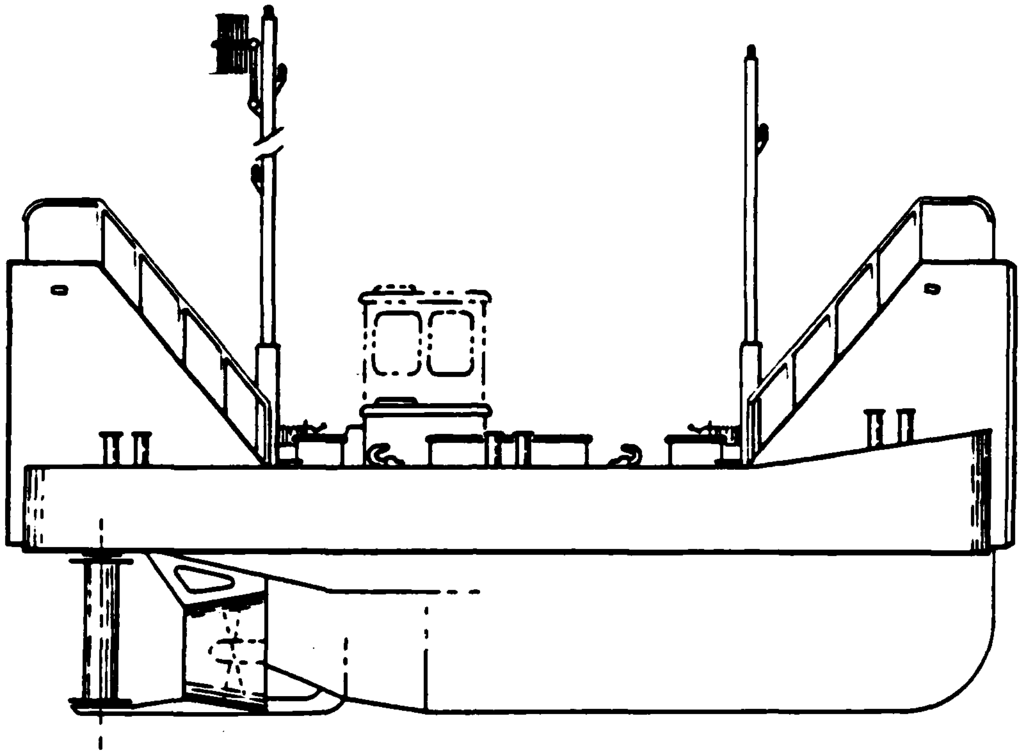
APPENDIX A

RESULTS OF BORG'S AND BORG/LUTHER GROUP'S RESEARCH TO DATE

In 1978, Steering Systems Incorporated, a subsididary of TBW Industries of Houma Louisiana, assigned John L. Borg the task of designing a radio controlled, unmanned bow tug. The purpose of this craft was to assist in maneuvering a long string of barges along inland waterways. The unit would be attached ahead of the lead barge and would be controlled by a microwave communication device from the bridge of the principal push boat at the stern of the barge train. When the steering force required to turn a quarter mile long raft of barges was computed it became obvious that conventional rudders would be inadequate for the task. The draft limitation imposed by the minimum depth of nine feet found throughout the waterways system would not allow the bow boat's rudders to have sufficient area to be effective. Some sort of dynamic steering system was called for. Cost factors ruled out the use of steerable propellers or thrusters. Borg proposed a twin hull configuration steered by a pair of cylindrical Magnus effect rudders. Calculations indicated that an impressive turning force could be produced by rotary rudders but verification was needed.

Little data was available concerning the behavior of the Magnus effect under water. Virtually all of the experimentation with rotating bodies in a flow were carried out in wind tunnels using air as a medium. Tests of Magnus effect rudder configurations were carried out at the Lockheed Ocean Towing Basin (now Rohr Marine Industries), in San Diego in the summer of 1979. The first run used a 15 inch long by 3½ inch in diameter aluminum cylinder having 7 inch diameter end plates and was positioned 6 inches beneath the surface of the water. At first inconsistent results indicated that ventilation may have been occurring so it was decided that the diameter of the upper end disk be increased to 12 inches. The enlarged upper pressure field yielded more reliable data. The little rudder worked so well in fact that higher velocities threatened to damage the overhead track due to excessive torque and forward speed had to be limited. Coefficients of lift were plotted and found to fall neatly parallel with the curves of Flettner and others, the models conformed to theory (see Appendix B for test results).

A two-lobed auto rotor was also tested at the same time. It was an unreliable self-starter so in true Gustav Magnus tradition a string was wrapped around the shaft to furnish starting torque.



"BOWMASTER"

ROBOT BARGE STEERING CATAMARAN
WITH TWIN MAGNUS EFFECT RUDDERS

LENGTH	50'-0"
BEAM	26'-0"
DRAFT	8'-0"
DISPLACEMENT	140.4 LONG TONS

FIGURE 33

This model was also 15 inches long and had an "S" shaped blade 7½ inches wide, both end plates were 12 inches in diameter. Its lift to drag ratio was a predictable 1:1. Although this test proved only that a two-lobed rotor was unsuitable as a propeller blade it was of historical interest in that it was probably the first time the magnitude of lift of an autorotor was measured in water.

During the time of the Lockheed Basin experiments, the Chairman of TBW Industries lost his life in a diving accident. As a result the "Bowmaster" robot towboat project was shelved and the prototype was never constructed. In an effort to stimulate more interest in Magnus effect steering systems a paper written by Borg was presented at the New Orleans Workboat Show in the fall of 1979. A working model composed of an electric outboard motor and variable speed plastic rotor was demonstrated in a stock tank filled with water. The model was again shown at the Offshore Technology Conference in Houston the following spring (Figure 34).

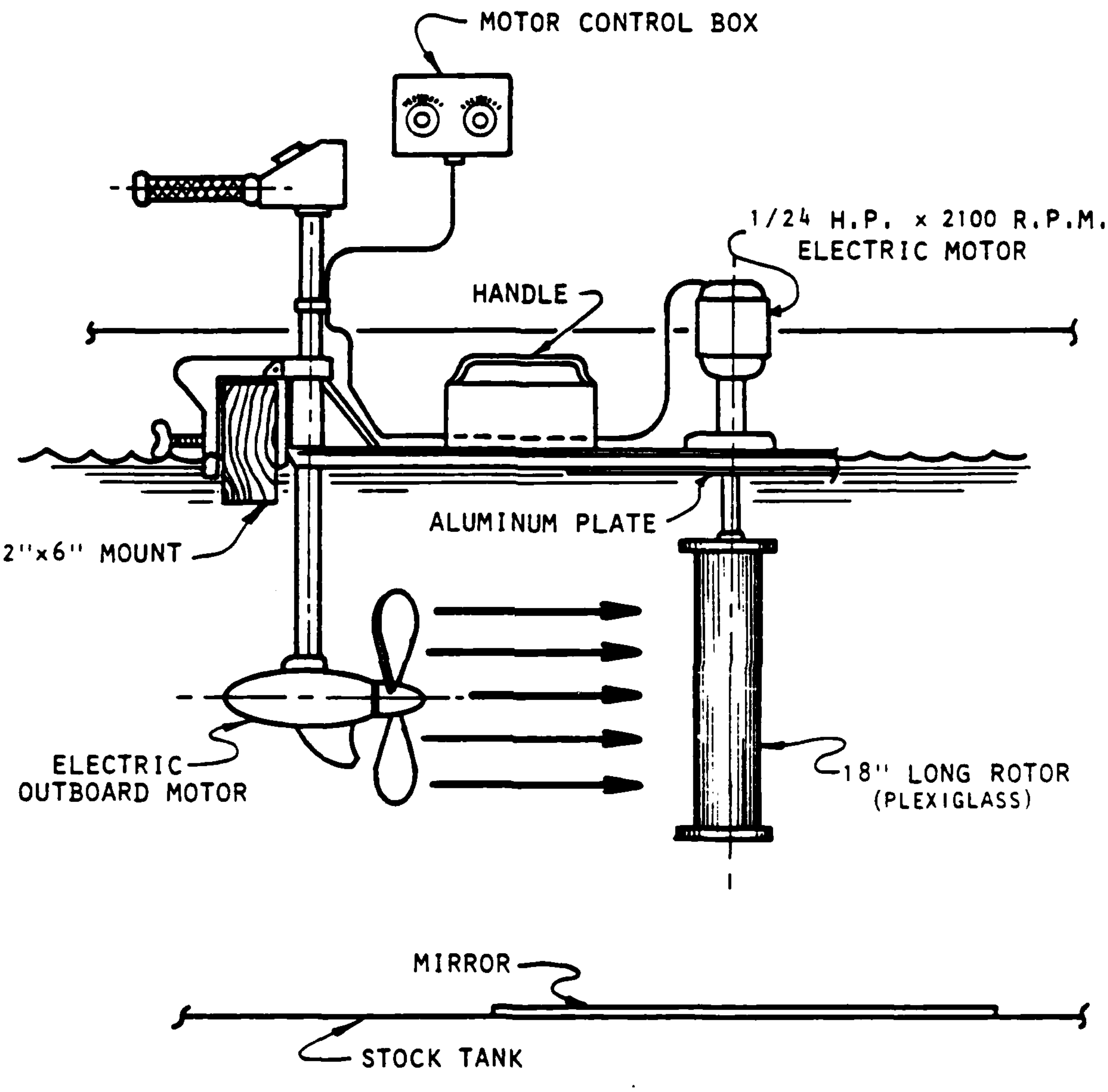
Impressed by the demonstration, the management of the Warrior and Gulf Navigation Company of Chicksaw, Alabama agreed to try a Magnus effect steering system on one of their towboats.

In the summer of 1980 the 65 foot twin screw pushboat "Escatawpa" was outfitted with a pair of cylindrical rudders 20 inches in diameter and 72 inches long, the end plates were 40 inches in diameter (Figure 35). These steering units were rotated by hydraulic motors within watertight tubs so that an entire assembly could be unbolted, lifted out of a well in the deck and be replaced without the services of a drydock (Figure 36).

When tested at dockside the rotors failed to reach the desired rpm. The frictional losses generated by the large endplates had been underestimated and a decision was made to remove the uppermost disk on each rudder relying on the bottom of the hull to furnish an adequate pressure field. This modification resulted in a 25 percent improvement in rotational velocity and the boat was ready for trials.

The change in the craft's maneuvering characteristics was impressive. She could turn in her own length from a dead stop and retained full steering capability at very low forward velocity even with both propellers stopped. With the rotors turning at full speed the propeller wake was observed to be deflected 90 degrees with respect to the centerline of the hull (Figure 37). The shift of the wake in this surprising manner had not been mentioned in any Magnus effect literature.

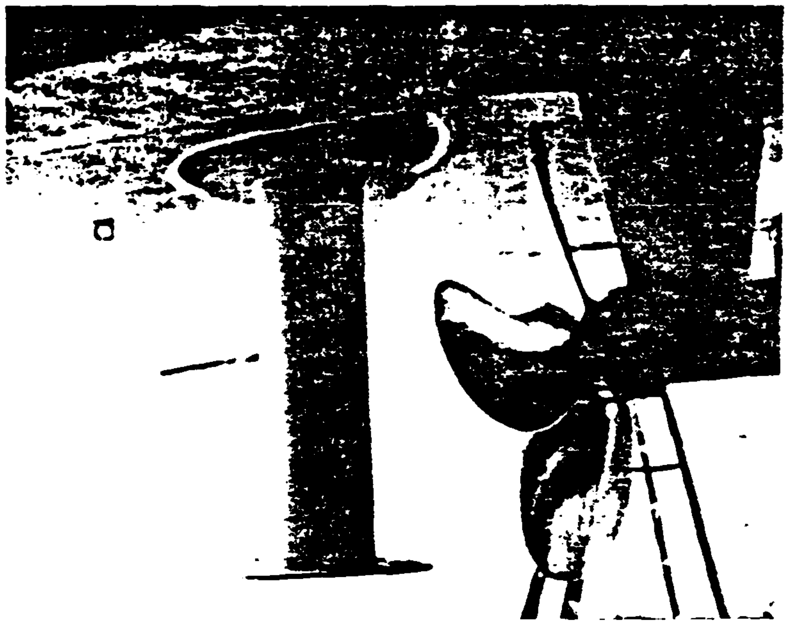
The extent of this shift in turbulence was not anticipated as a design factor in a twin rudder installation. The force was so strong that it tended to cancel the effectiveness of the rudder nearest the inside of the turn. To overcome this deficiency,



MAGNUS EFFECT RUDDER DEMONSTRATION MODEL

(DISPLAYED AT NEW ORLEANS WORKBOAT SHOW AND O.T.C. IN HOUSTON)

FIGURE 34

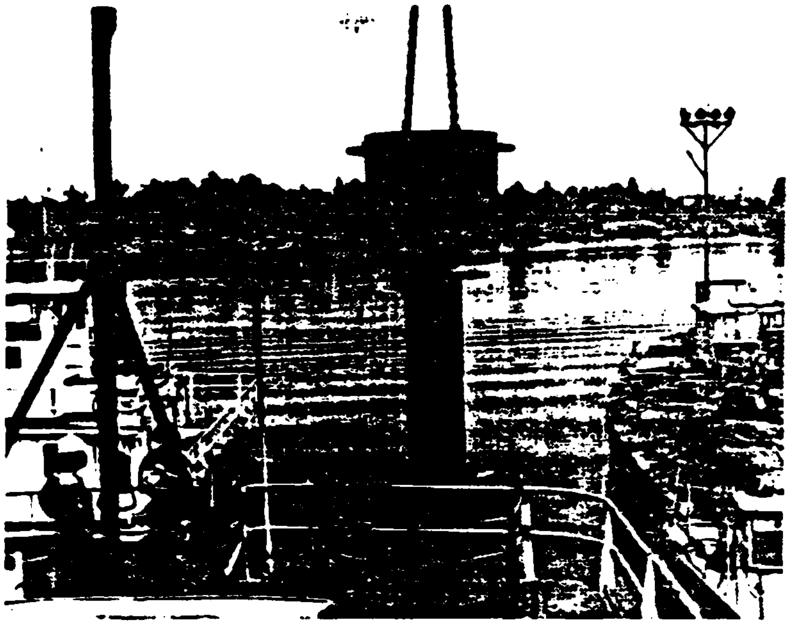


PORT RUDDER

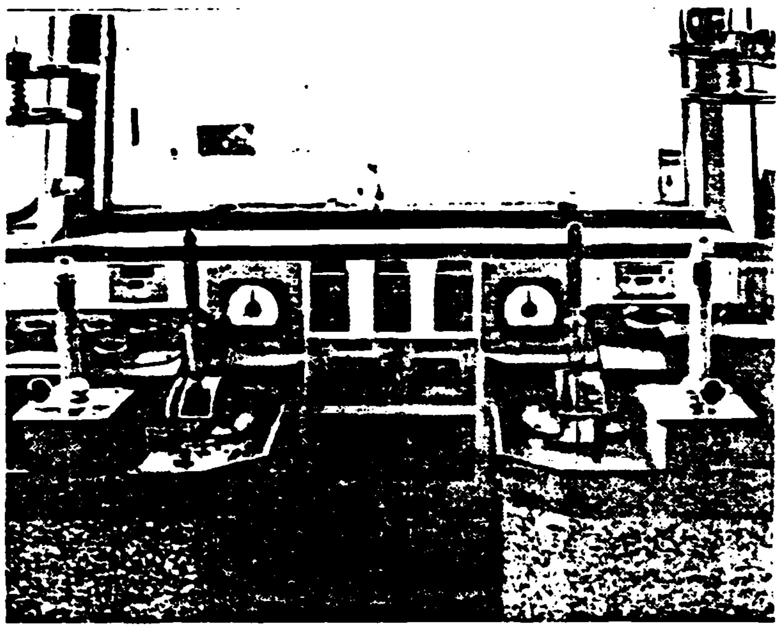
PORT RUDDER, LOOKING FORWARD

ESCATAWPA MAGNUS EFFECT RUDDER INSTALLATION

FIGURE 35



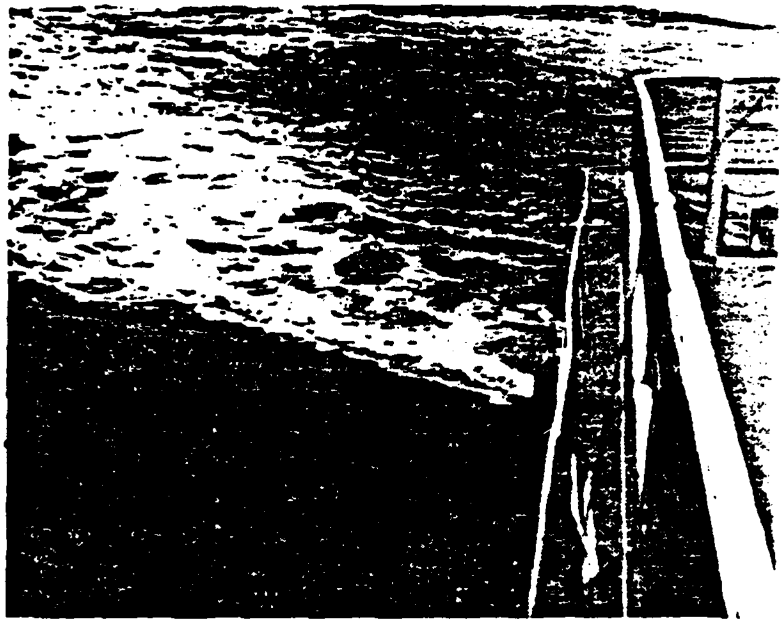
RUDDER BEING INSTALLED FROM ABOVE



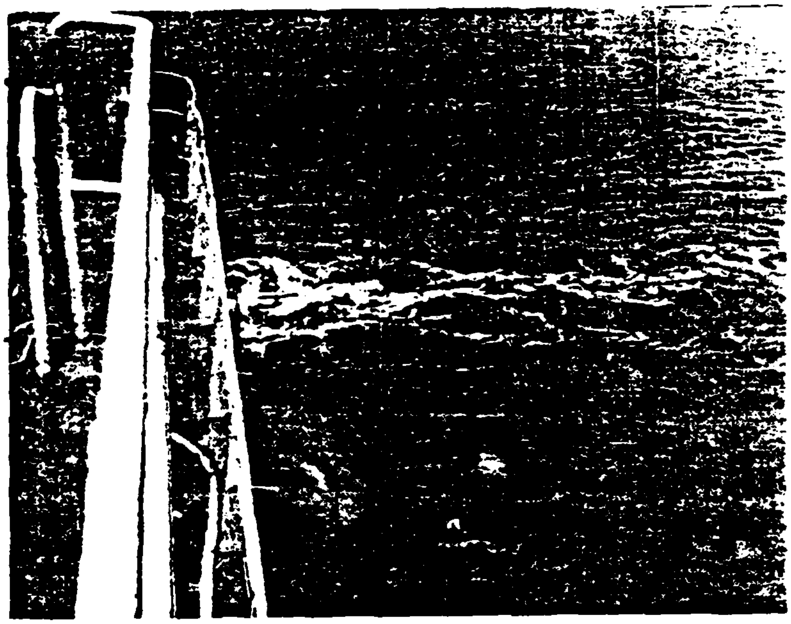
PILOT HOUSE, MAGNUS EFFECT RUDDER CONTROLS LOCATED OUTBOARD OF THROTTLES. ROTOR RPM AND DIRECTION INDICATORS MOUNTED ON FORWARD BULKHEAD.

ESCATAWPA MAGNUS EFFECT RUDDER INSTALLATION

FIGURE 36



PROPELLER WAKE DEFLECTION WHILE UNDERWAY, "STARBOARD RUDDER".



PROPELLER WAKE DEFLECTION WITH NO WAY ON, FULL "PORT RUDDER". NOTE THAT WAKE IS DEFLECTED 90°.

ESCATAWPA PROPELLER WAKE DEFLECTION WITH MAGNUS EFFECT RUDDERS

FIGURE 37

twin rudders might be staggered in future installations, minimizing inter-rudder interference. A similar problem in early aircraft design was solved by staggering biplane wings so that the downwash from the upper wing did not tend to disturb the lift of the lower one. The helmsmen of the Escatawpa learned that only one rudder was needed for minor changes in course. For more drastic maneuvers both rudders could be used but the one on the outside of the turn was held to a lower rpm so that its wake was not deflected a full 90 degrees.

The controls of the two steering rotors were independent of each other, enabling the boat to accomplish such tricks as "walking" sideways. Eventually one of the steering units become damaged when it was run aground. It was simply turned off and the towboat continued on, using only one rotor, a feat that would have been difficult with conventional rudders having tillers connected by a jockey bar.

The hydraulic pumps used with the Magnus effect system required more power than the towboat's somewhat undersized diesel generator could furnish. An extra diesel powered hydraulic system was installed for greater operational reliability.

Utilizing the new steering system the Escatawpa was now able to control six 36 foot by 195 foot barges rather than the customary 4 barges, an increase in cargo capacity of 50 percent. Since it no longer lost headway due to rudder drag, it was able to overtake towboats having twice its horsepower while negotiating turns in the river.

In spite of this promising performance and over the protests of the general manager of Steering Systems Incorporated, the directors of TBW Industries chose to discontinue further development of Magnus effect steering systems. One possible explaination for this decision might be that patent protection was nearly impossible. Because of the W. Roos patent of 1929, cylindrical rudders were in the public domain (see Chapter 4).

In 1981 Borg experimented with autorotating propeller blades without success. Convinced that this approach to Magnus effect propeller design was impractical he designed and filed for a patent of the nozzled propeller with friction driven rotors.

Joined in 1982 by an associate, William B. Luther, the Borg/Luther Group was formed with the intent of designing a Magnus effect rudder for a 35 foot tuna seine skiff. Tests of this system led to the disappointing discovery that the propeller wake deflected by the rotary rudder impinged upon the basket-like net protecting structure around the stern, greatly reducing steering effectiveness. Thus another lesson was learned about Magnus effect rudders. That is that they must be located in the open: they would not be effective, for instance, installed between the hulls of a catamaran.

The seine skiff builders were unwilling to compromise the design of the net protecting steel gridwork for better maneuverability. As a result rotary rudders did not become popular with the tuna fishing industry.

The Borg/Luther Group continued to experiment with various autorotor configurations. This work led to the development of the "Tuborotor". This three lobed, self-starting rotor has the best characteristics of any autorotor tested to date (Figure 38). Several successful horizontal and vertical axis model windmills were constructed for demonstration purposes. Although small, these models clearly show that tremendous torque can be produced by Magnus effect windwheels.

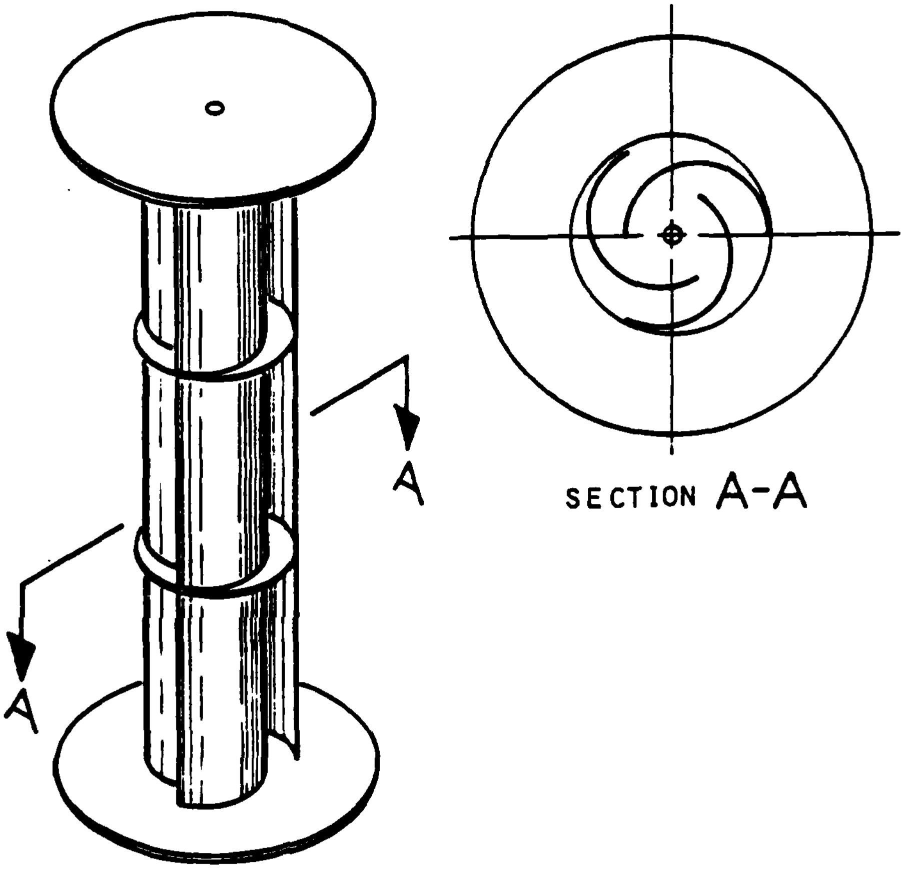
A one-quarter horsepower Magnus effect propeller having friction driven rotors was constructed of inexpensive materials. It is approximately 4 feet in diameter and generates wind velocities of ten miles per hour. This model proved that there is nothing wrong with the rotor blade propeller concept.

Borg/Luther determined lift to drag ratios of various rotor designs by measuring their glide slope. When a plain cylinder with end plates was tested a string was used to impart the proper spin. Rather than glide, the little rotor rose to an altitude of about 25 feet and executed a graceful loop. Then since there was a light breeze blowing, it hovered in perfect equilibrium several feet above the ground and finally glided to a landing. With a little skill and proper wind conditions the performance of the "Rotorang" could be duplicated by anyone. Study of the flight path of this toy was of great assistance in visualizing how the Magnus effect works as surface and wind velocities change (see Figure 9, page 22).

A patent has been issued for a vertical axis, Magnus effect energy converter. The design attempts to solve the problem of wrong-way rotation of the rotor on the downwind side of the orbit by having it flip itself over. Further work has been done with this concept and larger prototypes are to be constructed in the near future.

The Borg/Luther Group has also addressed the problem of tacking a boat propelled by autorotating sails. (Figure 11) The situation is similar in some respects to that of the vertical axis converter. This project has been put on the back burner due to the doubtful value of autorotors as opposed to Flettner type sails.

During the past five years of Magnus effect investigation, the Borg/Luther Group has managed to amass an impressive volume of lore, analysis technique and application concepts related to the subject. Most of this information has been made available in this study for use by the Navy.



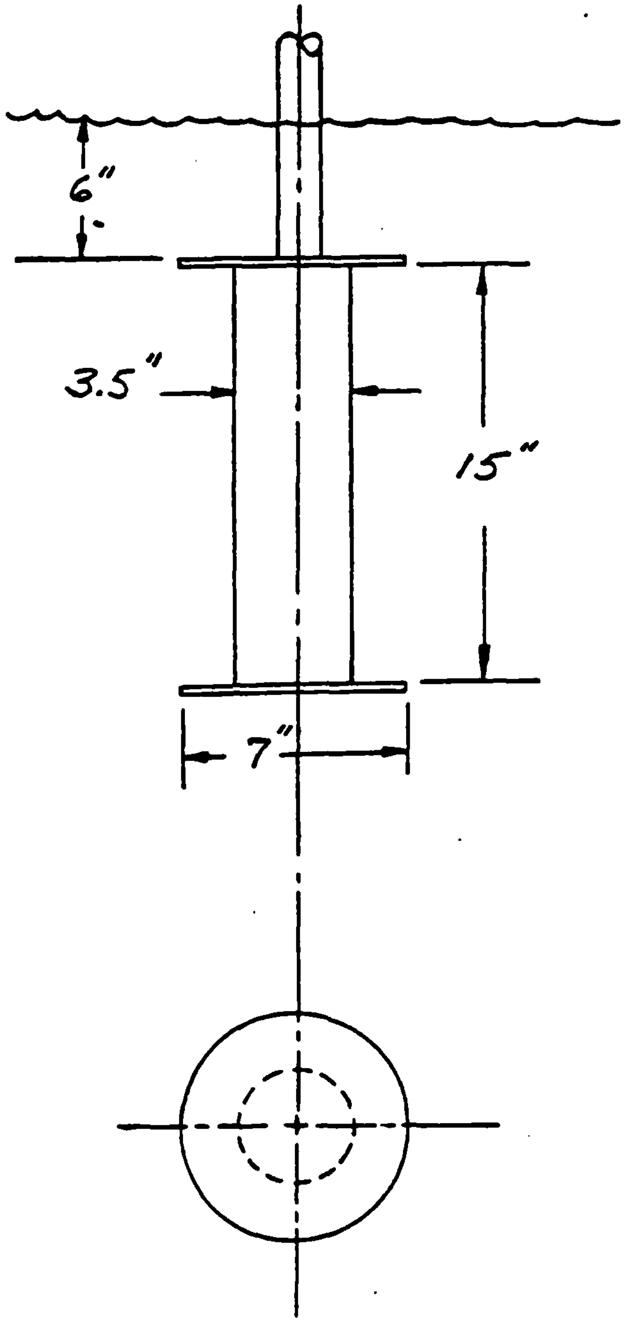
THE BORG/LUTHER TURBOROTOR

FIGURE 38

APPENDIX B

Model sketches and curves of performance resulting from tests of two Magnus effect dynamic rudders, conducted by the Lockheed Ocean Laboratory, 3380 North Harbor Drive, San Diego, California, August, 1979.

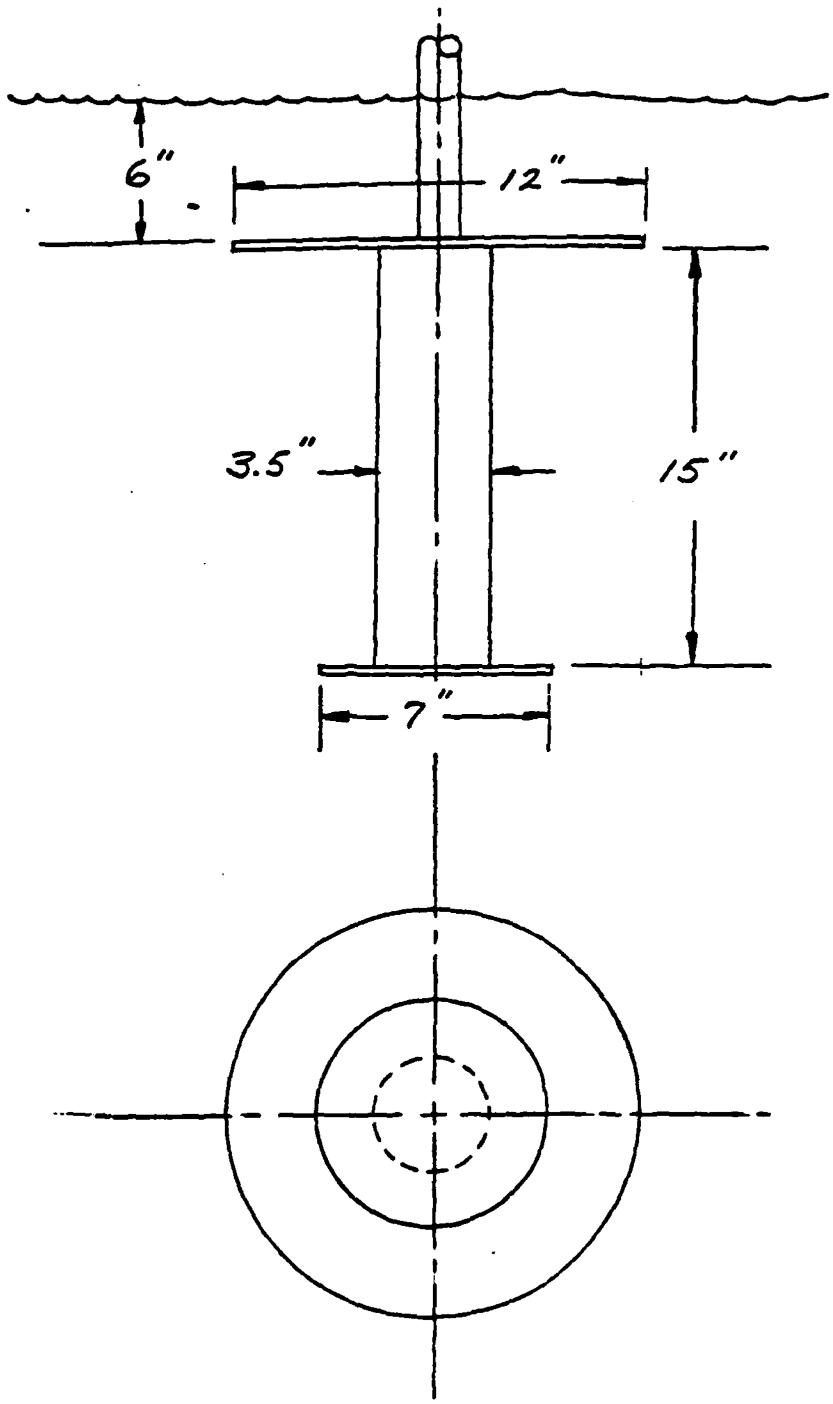
TEST MODELS



MODEL NO. 1

FIGURE 39

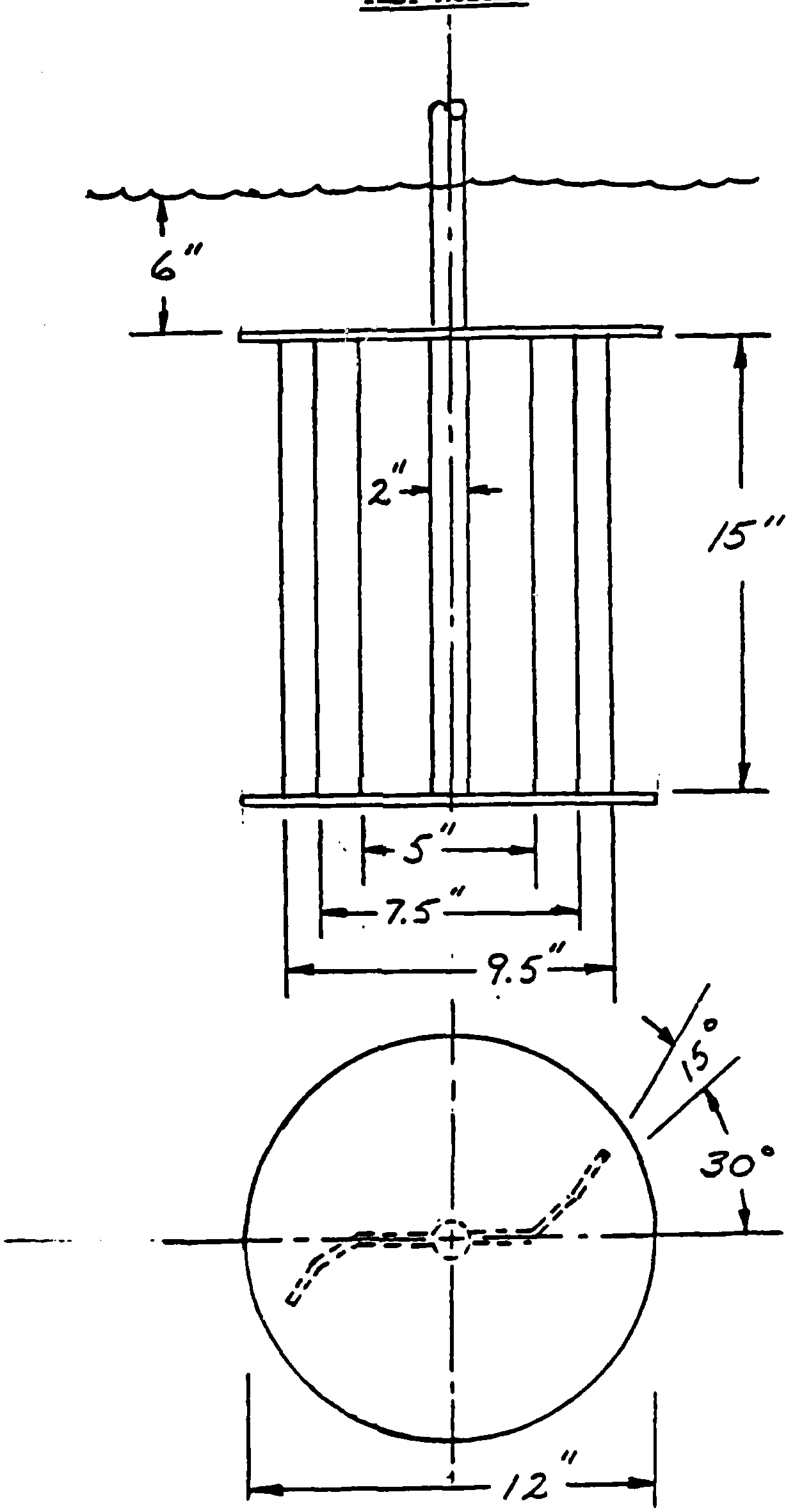
TEST MODELS



MODEL NO. 2

FIGURE 40

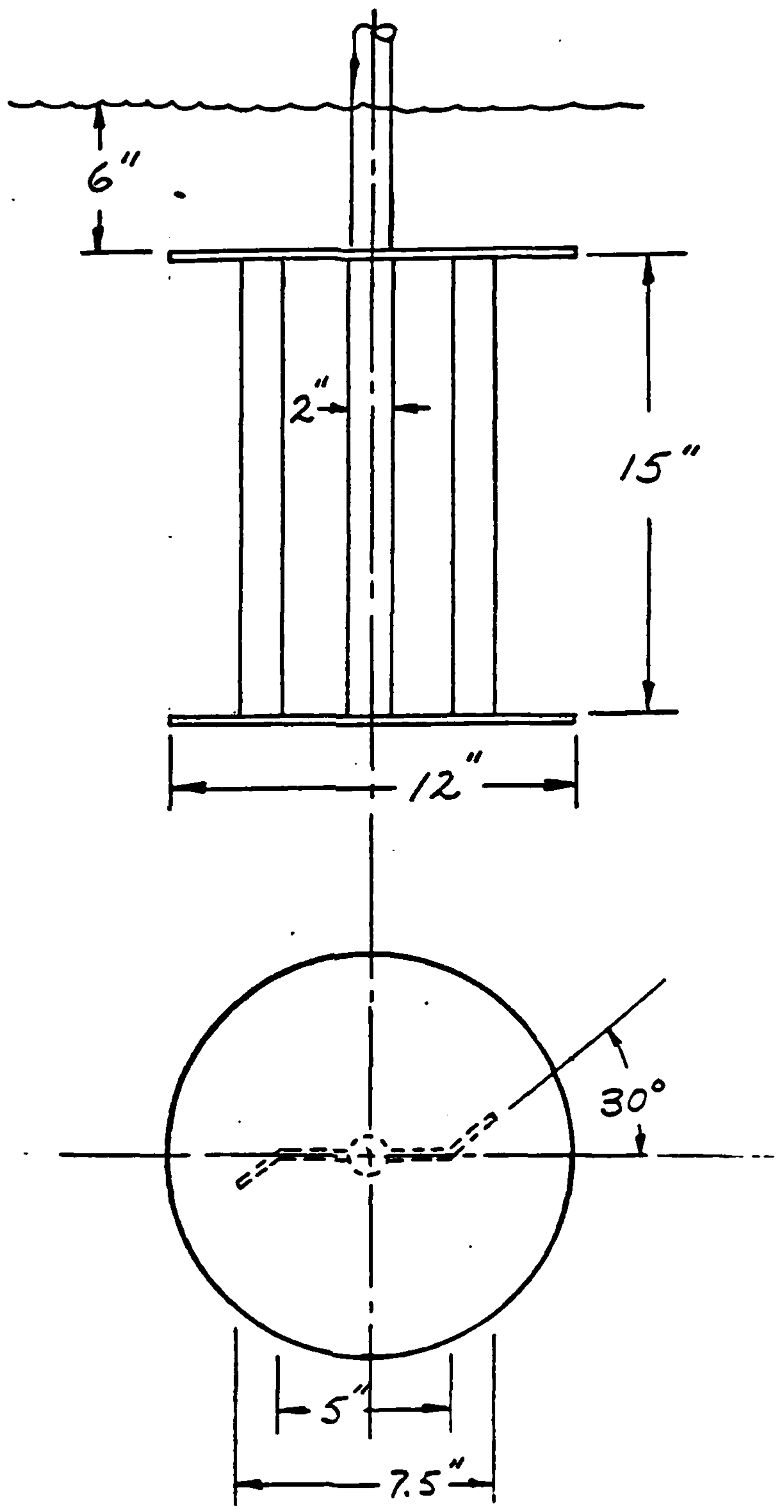
TEST MODELS



MODEL NO. 3

FIGURE 41

TEST MODELS



MODEL NO. 4

FIGURE 42

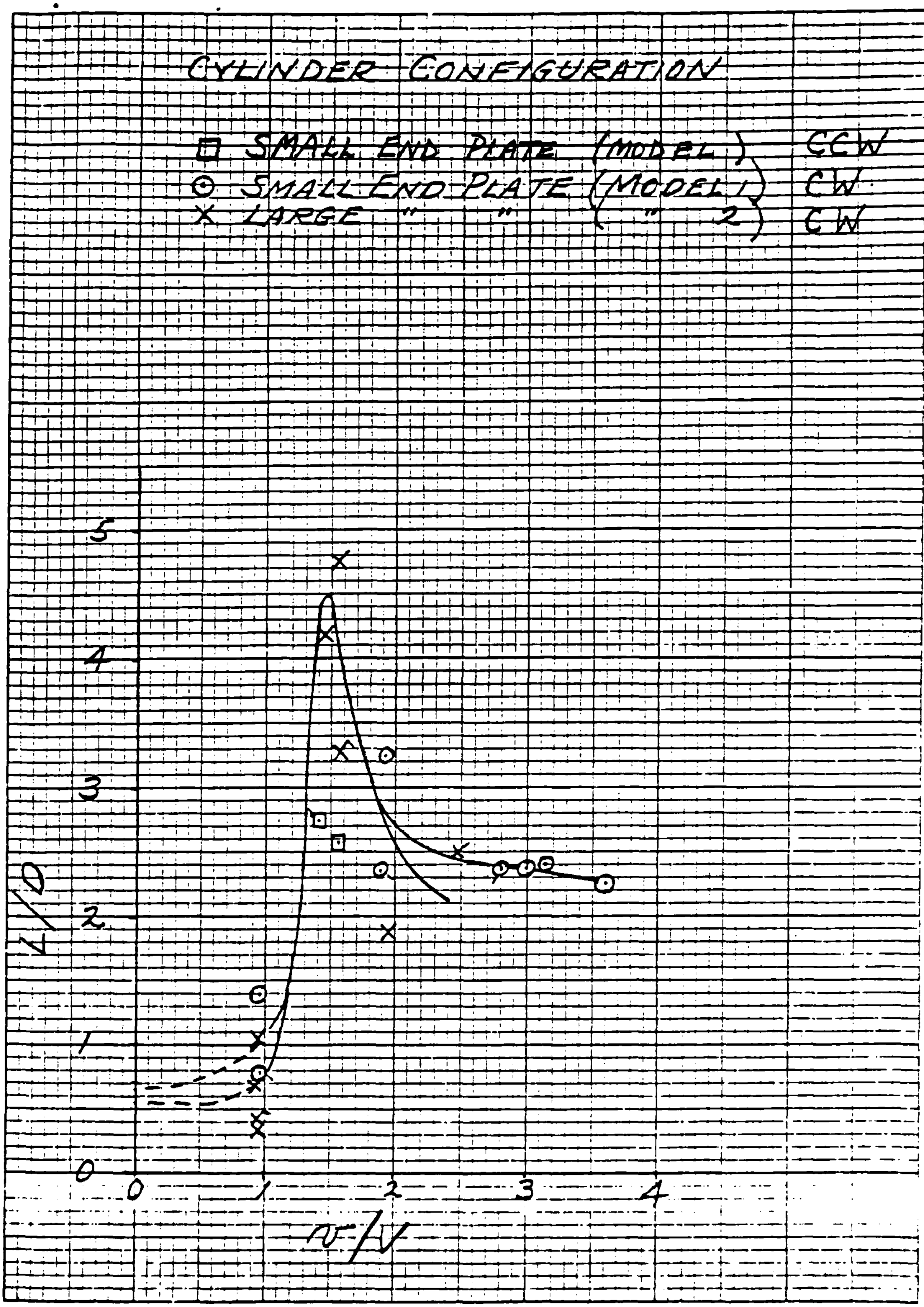

CYLINDER CONFIGURATION
□ SMALL END PLATE (MODEL) CCW
⊙ SMALL END PLATE (MODEL 1) CW
× LARGE " " (" 2) CW
L/D
0
1
2
3
4
5
0
1
2
3
4
v/V

FIGURE 43

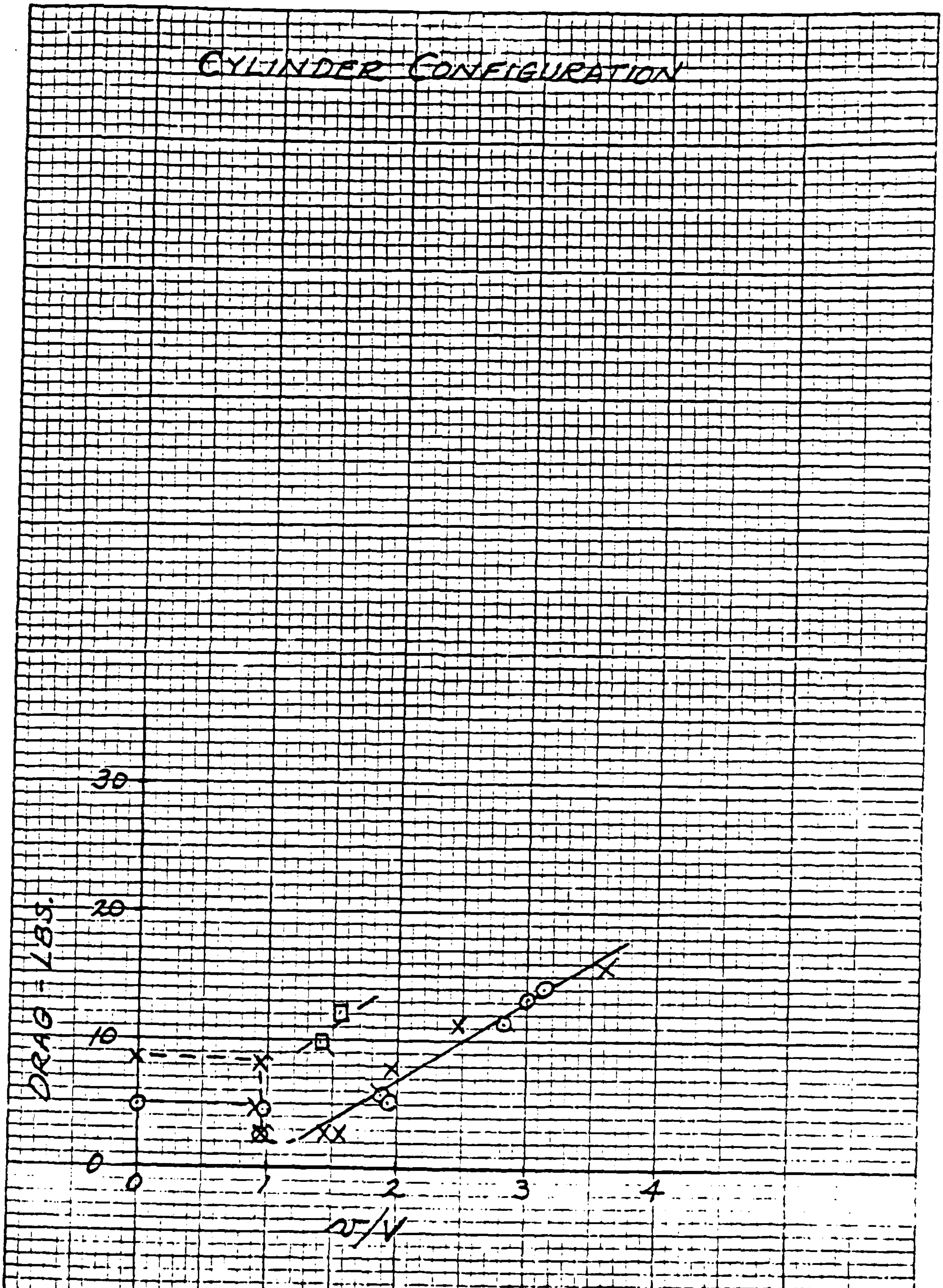
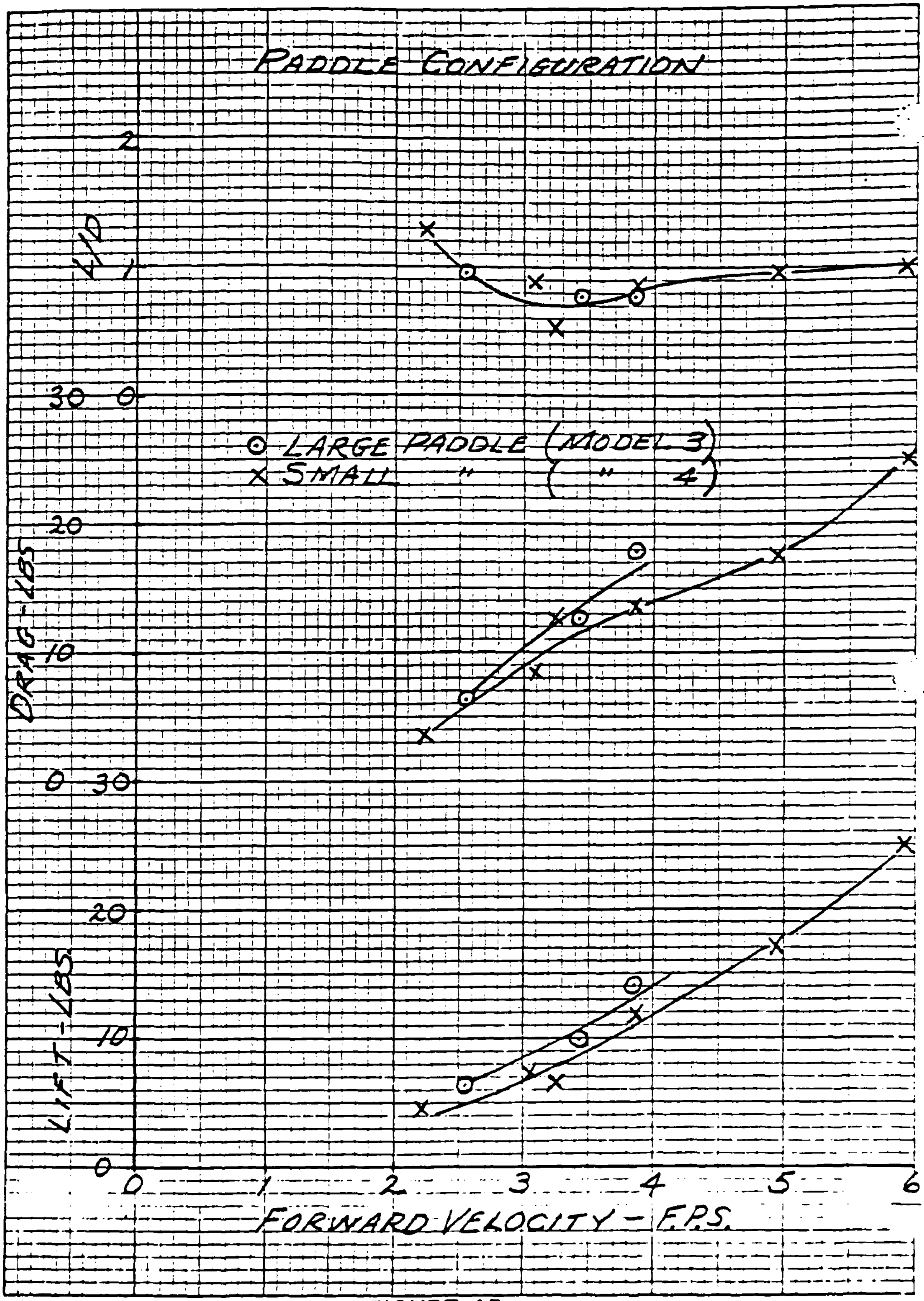


FIGURE 44



PADDLE CONFIGURATION
L/D
2
1
30 0
⊙ LARGE PADDLE (MODEL 3)
× SMALL " (" 4)
20
10
DRAG-LBS
0 30
20
10
LIFT-LBS
0
0 1 2 3 4 5 6
FORWARD VELOCITY - F.P.S.

FIGURE 45

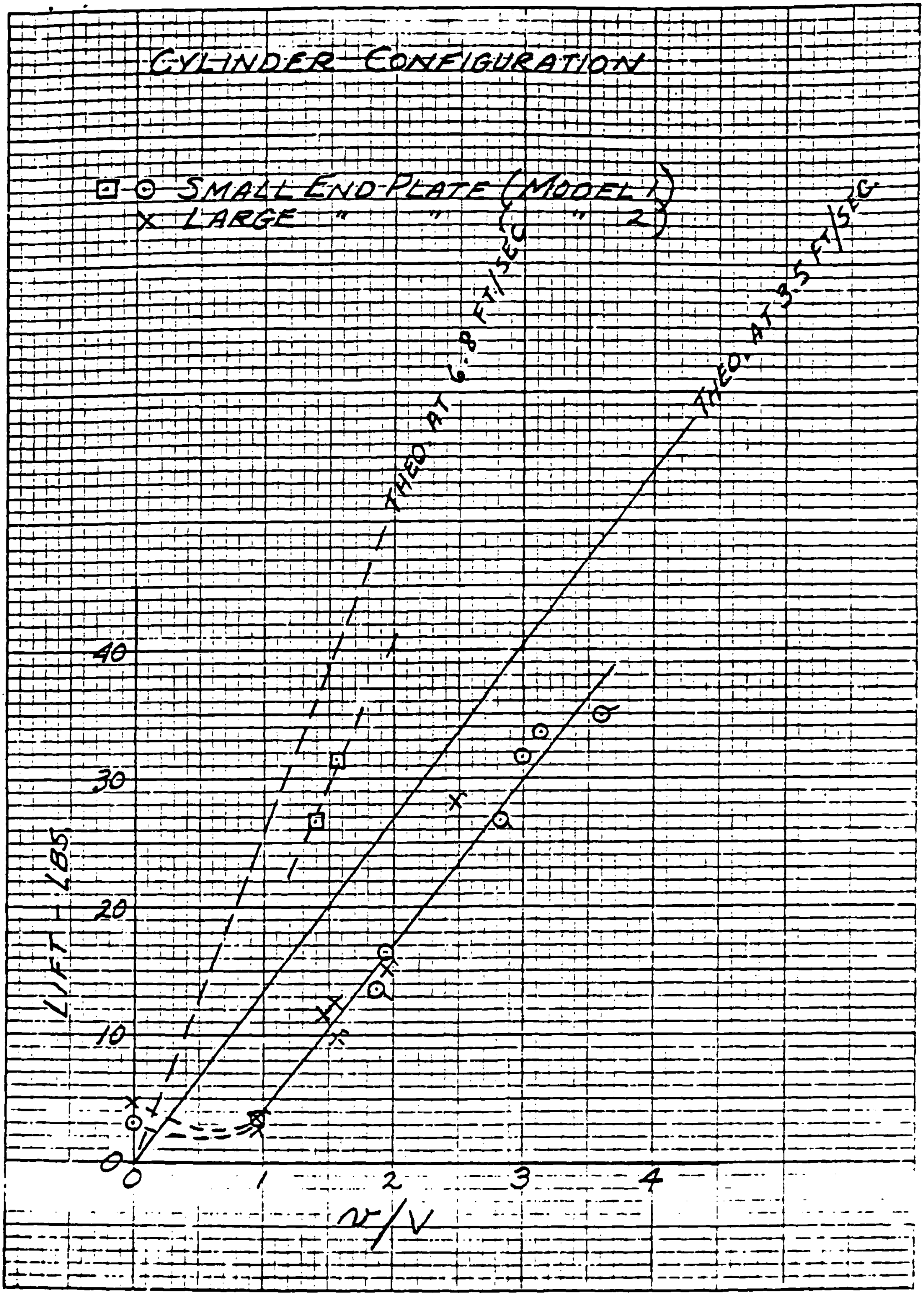

CYLINDER CONFIGURATION
SMALL END PLATE (MODEL 1)
× LARGE " " (" 2)
THEO. AT 6.8 FT/SEC
THEO. AT 3.5 FT/SEC
LIFT - LBS
40
30
20
10
0
0
1
2
3
4
v/V

FIGURE 46

APPENDIX C

A CRITIQUE OF MAGNUS EFFECT ORIENTED LITERATURE

"The Story of the Rotor", from the German "Mein Weg zum Rotor", written by Anton Flettner, published in 1926 by F.O. Wilhoft, New York.

The material encompassed in Flettner's semi-autobiographical book has been covered, for the most part, in Chapter 2 of this study. To avoid redundancy it will not be repeated here.

From the engineering rather than the historical standpoint a number of valuable concepts are revealed in this book. The text and illustrations are sufficiently detailed to allow others to duplicate his rotorsails and windwheel generators. The results of the model tests conducted at Gottingen wind tunnel are generously provided in the form of lift, drag, stability and performance curves. These frequently appear in subsequent Magnus effect literature.

Flettner does his best to explain the behavior of rotating cylinders in language that laymen can understand but is disappointingly stingy with his mathematical relationships. It has been pointed out earlier in this study that, in all probability, an equation that adequately describes the Magnus effect does not exist; but it would be nice to know how closely the experimental results compared with the theoretical predictions of Prandtl and others. Also missing from the book is the method he used for determining the horsepower requirements for the rotor drive systems.

Perhaps the most important feature of the rotor proposed by Flettner was the use of cylinder end plates. Without these, rotorsails would have been impractical because of the high aspect ratio requirement. He was aware of the need to seal off the tips of an airfoil prior to his involvement with the Magnus effect and had filed patents as early as 1920 for a rudder having end plates. He fails to tell us, however, the means he used to select the optimum end disk diameter.

Another valuable contribution by Flettner is the use of tapered rotors for windmill blades. No doubt he reasoned that the airflow should impinge perpendicularly upon the leading side of the cylinder. Any yaw in the direction of the airstream in relation to the axis of the rotor could result in less than maximum lift. Flettner seems to have accepted Professor Prandtl's suggestion that the maximum lift of a rotor was limited to a coefficient of lift of around four pi (4π). The coefficient of lift curve shown in the book goes horizontal at a lift coefficient of ten. This suggestion was later proven to be incorrect but was taken as fact by a number of Magnus effect inventors. Flettner also stressed the importance of vibration control in rotorsail installations and this advice should certainly be taken seriously by engineers working with the Magnus effect.

The first rotorship described in the book was a retrofit and therefore imposed limitations regarding the ideal locations for the cylindrical sails. The positions of the original mast steps of the Baden-Baden dictated the rig profile. The distribution of rotors is too far aft and should not be used for guidance in future installations.

In the final pages of his book, Flettner berates the people of little imagination who make life difficult for inventors. He can be forgiven for this little digression in view of his impressive accomplishments.

It is well to remember that "The Story of the Rotor" has virtually been the sole source of Magnus effect information available to the public for over half a century. It should be regarded as a classic piece of engineering literature.

"The Magnus Effect Propulsion", by P.A.M. Spierings, published in May 1980, source unknown.

This brief paper of six pages begins with a short explanation and history of the Magnus effect. The author notes some drawbacks about the Flettner rotor ship Baden-Baden such as "-the absence of steadying of the rolling motion as in the case of sails, and the limited capability of the rotor arrangement under high wind conditions." He states that "both Flettner's and Madarasz's projects terminated shortly after initial demonstration." Flettner's own book, "The Story of the Rotor," is not cited as a reference.

Spierings goes on to expand on the relationship involved in lift generated by circulation as theorized by Prandtl including C_L max = 4 - and mentions that performance predictions using this theory are optimistic by 10%. Further on he mentions "the end plate obscures the core location of the vorticity and makes the problem description less defined. Under multiple use of rotors the mutual interferences may cause a significant departure from the one rotor three dimensional case."

Spierings offers the following formula to determine power to overcome the viscous drag of a rotating cylinder:

$$"HP = C_{df}\rho v^2 2\pi r \frac{RPM}{21000}$$

where the skin friction drag coefficient C_{df} is a function of the Reynolds number."

The rotor versus sail comparison summarized at the end of the paper relates to the performance of the Baden-Baden only and cannot be used for rotorships in general.

In the final paragraph of the paper there is a statement worth noting.

"Modern high strength to weight ratio materials will also reduce the pitch and roll coupling of the hull motion. The gyroscopic moments on the radidly spinning rotor(s) cause this coupling."

In a way, Spierings takes a rather old fashioned view of the Magnus effect in spite of the recent date of the paper. It contains nothing that could be considered a breakthrough in understanding the phenomenon. On the whole the article takes a somewhat negative stand on rotorsail propulsion but points out that new material and techniques might make it practical.

"Obervations on the Performance Possibilities of the Rotor Ship", by B. Wagner, Institute for Shipbuilding of the University of Hamburg, Publication No. 2035, June 1964, translated by Wind Ship Development Corporation of Norwell, MA.

Wagner begins his paper with a fairly detailed description of the two Flettner rotorships and their fate. He then develops a comparison between the Baden-Baden rigged as a hermaphodite brig (or schooner brig) and as a rotorship. The comparision was performed by computer and is presented in the form of course diagonals. The computations are clearly outlined and are quite detailed. He concludes that the rotorship is superior to the brig in winds up to force 5 (18 knots) when close-hauled and on broad reaches, but is inferior at angles to the wind greater than 110°. Naturally one expects the conventional sails to do better before the wind; they have 10 times the area of the rotors. As for the performance of the rotors in winds greater than force 5, the surface velocity was held to $v = 17.6$ m/s. Wagner admits that if the rotor rpm was allowed to increase, the rotorship would be better than the brig at all windspeeds. He further penalizes the rotors by limiting the velocity ratio, saying, "in order to prevent the risk of a change from laminar to turbulent flow, the ratio u/V_A (or v/V in the notation used in this study), was limited to 3.5 where necessary by reducing the peripheral velocity u (or v)." He neglects to explain about this so-called "risk."

Wagner goes on to enumerate the advantages and disadvantages of the rotor ship compared with sailing ships of the era. The advantages are:

"(1) The rotor ship requires a smaller crew, since the sailing techniques have been simplified.
(2) The ship is ready to get underway more rapidly since making and furling sail is unnecessary.
(3) Good maneuverability, tacking and jibing may be assisted by reversing the forward or aft cylinder.
(4) Good speed at low wind velocities, especially close-hauled and with a following wind.

The following disadvantages of the rotor ship may be mentioned:

(1) The power required to turn the rotors.
(2) Limited utilization of the higher wind velocities when the peripheral velocity of the rotors is limited. Because of this the rotor ship's maximum speed attainable at higher wind velocities is significantly less than those of a comparable sailing ship.
(3) Poor sailing characteristics before the wind, making it necessary to come about before the wind (tack downwind).
(4) Unfavorable behavior of ship in a seaway. The rotors exhibit significantly less roll-stabilizing than sails because the forces on the rotors are independent of the angle of attack.
(5) Rotors subjected to heavy stress in rough weather."

If Wagner had mentioned the "hurricane-proof" feature of rotor sails, the number of advantages and disadvantages would have been equal. On the final page of his observations is this statement.

"If an ideal rotor is compared with an ideal sail, then it turns out that, even when the power necessary to turn the rotors is disregarded, the sail is superior to the rotor, if the projected area of the rotors is chosen proportionally to the sail area so that the upsetting moments are equal."

The last phrase of this statement is an absurdity. Because of its high coefficient of lift, a rotor will always have only a fraction of the area of a sail capable of equal thrust. The only way to comply with Wagner's comparision by means of equal capsizing moments would be to elevate the rotorsails on very high towers above the deck and there is no good reason to ever do that. His final conclusion is:

"Even today development of the sail appears more promising than continued development of the rotor principle in order to use the wind to drive ships."

Wagner's paper should not be taken seriously as a comparison of sail versus rotor. He takes advantage of some conceptual and mathematic tricks to make the rotors look bad. This attitude is understandable when one considers the source. Since 1956 extensive research was being carried out at the Shipbuilding Institute on the "Dynaship" concept. It would have been inconsistant to favor rotorsails over the high aspect ratio, square rigged configuration in vogue there at the time.

"Windkraft vom Flettnerrotor", (Windpower from the Flettner rotor), by Felix von Konig, published 1980, Udo Pfriemer Verlag Munchen (NAVSEA Translation No. 2059).

The cover subtitle says "Boats, Yachts, Ships and Windwheels with Rotors." The entire book including a supplement entitled "How to Construct a Flettner Rotor" consists of 160 pages with 63 illustrations as well as 30 equations relating to Magnus effect applications.

The author has managed to compile a virtual encyclopedia of windrotor lore and present it in a popularized form for the do-it-yourself rotor buff. He even includes a chapter on rotor propelled land vehicles and detailed instructions on how to construct your very own fiberglass rotor in the garage. His step-by-step explanations of the mathematical relationships involved in Magnus effect applications are understandable enough to be used by anyone with a high school education (or at least with a German high school education). Unfortunately the symbols and notation are somewhat different than those commonly used in the U.S. and no table of nomenclature is provided. The units used are metrics so that a symbol such as ρ (rho) means simply density and not mass density as applied in the English measurement system. For these reasons, a serious reader would be wise to "translate" the equations for easier comprehension.

An interesting observation by von Konig deals with wake generated by a rotor. He notes that at a velocity ratio of four the high pressure point swings past ninety degrees and actually points somewhat into the flow. This of course accounts for a lower lift to drag ratio at $v/V = 4$, but he follows up with a disastrous misconception, saying, "if one increased the speed more and more, the air deflected by the rotor would soon form a circle and the overpressure (e.g. high pressure), zone would be forced away by the rotor and would have no further effect on the rotor. C_L would be equal to 0". This is not true, with properly designed rotors lift continues to increase with higher velocity ratios, although in some cases, at a slower rate.

The author also offers this relationship: "the Flettner rotor requires an auxiliary force of 2-3% of its output to operate. This force could theoretically be derived from the wind." This value is less than that indicated in other studies.

A large portion of the book is devoted to wind wheels. The Flettner generator is analyzed noting that it is a very high torque, low rpm machine and requires an expensive gearbox. He offers two vertical axis concepts that may have merit.

The first is a version of the Madarasz system, rotors on a circular track which is a linear motor. Thus the track serves as a generator. The second system is a vertical axis turbine mounted above a horizontal axis rotor used to deflect a flow of air upwards. This system can be installed atop a building and is more compact and esthetically pleasing than a horizontal axis unit.

Although some of von Konig's statements about the behavior of rotating cylinders are conjecture and should not be trusted, his book is, nonetheless, so full of ideas about Magnus effect applications that it is well worth studying. It does not, however, contain any new theoretical concepts or test information and relies mainly upon the same Gottengen data used by Flettner.

"The Magnus Effect: A Summary of Investigations to Date", by W.M. Swanson, published in the Journal of Basic Engineering, Transactions of the ASME, September 1961.

The Swanson paper is one of the most comprehensive and reliable sources of Magnus effect information presently available. Quoting, in part, from its abstract:

"-A great deal of effort has been expended in attempts to predict the lift and drag forces as functions of the primary parameters, Reynolds number, ratio of peripheral to freestream velocity and geometry. The formulation and solution of the mathematical problem is of sufficient difficulty that experimental results give the only reliable information on the phenomenon. This paper summarizes some of the experimental results to date and the mathematical attacks that have been made on the problem."

In the first portion of his paper, Swanson discusses Magnus effect behavior, its history, and the work of its principal investigators. A very useful set of curves and a summary of previous lift coefficient versus velocity ratio data is provided. He mentions that "the most complete experimental work was done by A. Thom at the University of Glasgow and was reported in his doctoral dissertation and in five Reports and Memoranda of the British Aircraft Research Council during a nine year period from 1925 to 1935. The effects of Reynolds number, surface condition, aspect ratio and end conditions were investigated. Pressure, velocity and circulation data were also obtained."

Further along in the text the author again speaks of Thom's work, saying, "These results along with those of other investigators are of primary interest in indicating the effect of finite aspect ratio. The smaller the aspect ratio, the smaller the maximum lift obtained and the smaller is the velocity ratio at which this maximum is reached."

The author points out that end disks give entirely different flow conditions from those of an infinite aspect-ratio cylinder and no combination of disks on a finite cylinder would be expected to produce conditions similar to those for an infinite cylinder.

The closest approach to infinite cylinder conditions is believed to have been obtained W.M. Swanson himself using a three-sectional apparatus which he describes as: "A live cylinder section mounted on a long shaft supported by cantilever strain-gauge beams was flanked by dummy cylinders running on shafts concentric with the main shaft. All three sections were spun simultaneously using couplings that transmitted torque, but negligible transverse thrust. A very close clearance (0.010 to 0.015 in.) was maintained between the six inch diameter cylinder sections. The dummy cylinders were also extended through the wind tunnel walls with a close clearance to obtain minimum end effect."

"One of the primary objectives of this investigation was to determine whether or not a maximum (peak) lift coefficient indicated by Prandtl would be obtained for an infinite aspect ratio cylinder. None was obtained and it can be seen that the Magnus lift was still increasing uniformly at a velocity ratio of 17."

Swanson's curves show that at $v/V = 17$, $C_L = 14.8$ and $C_D = 1.6$ representing an $L/D = 9.25$. The high lift coefficient of the infinite cylinder is impressive when one considers that the C_L of an aerodynamic airfoil ranges from 1.25 to 3.

The author is very concise in his explanation of the behavior of the boundary layer of a rotor at various velocity ratios and Reynolds number values and provides useful diagrams to clarify the discussion. His description of the hump in the C_D curve is particularly interesting. He uses the Greek letter α to represent the velocity ratio v/V.

"As α increases beyond 1, the drag, surprisingly, increases to a value greater than the drag on the non-rotating cylinders, even though the wake area is decreasing. This large drag increase with increasing α is accompanied by a movement of the rear stagnation point and the wake in a counterclockwise direction into the region near the bottom of the cylinder. The drag peaks in the region where the lift knee occurs. The boundary layer origin is at the top of the cylinder and the separation points and wake are near the bottom of the cylinder. An increase of α as described produces a further rotation of the wake toward the front of the cylinder. The resulting flow pattern and pressure distribution produce a decrease in C_D."

The point of all this is that more favorable lift to drag ratios will be obtained by avoiding the hump that materializes in the neighborhood of v/V = 4.

Swanson provides us with what is probably the best mathematical model for Magnus effect coefficients of lift and drag:

$$C_L = [1 - (\frac{a}{c})^2]K_\alpha\alpha + \frac{\sin\gamma}{2\pi} (\frac{a}{c}) (K_\alpha\alpha)^2$$

and

$$C_D = - \frac{\cos\gamma}{2\pi} (\frac{a}{c}) (K_\alpha\alpha)^2$$

Where:

K_α = a factor relating velocity ratio and circulation

or $K_\alpha = \frac{1}{\alpha} \frac{\Gamma}{aU_\infty}$

a = cylinder radius

U_∞ = free stream, uniform velocity of approach at x = ∞

Γ = circulation

α = v/V

γ = argument of location of external vortex

c = radial distance to external vortex

He follows these equations with the remark, "Unfortunately, there is no way by which c/a (α), γ (α) and K_α (α) can be determined." Which puts us back in the wind tunnel again.

One must read Swanson's paper at least ten times so as to be sure not to miss anything but its worth the effort to gain a better understanding of Magnus effect.

"Marine Aerodynamic Device with Enhanced Efficiency," discussion by G.M. Kudrevatyy, V.P. Khudin and B.N. Zakharov, Sudostroyeniye, No. 2, 1983, pages 14-18, (from the USSR).

The primary intent of this wing rotor is to improve performance before the wind, which is admittedly one of the faults of a Flettner rotor. The coefficients of lift obtained from the model tests are not very impressive. The maximum C_L obtained was only 2.35, which looks good when compared with the Dynaship with C_L = 1.5

but not with an unadorned rotor having a $C_L = 10$. Of course the wing rotor is better downwind because its thrust is generated by a greater area of drag. In other words they have sacrificed the high performance characteristics of the rotor in order to improve those of the flat sail.

Only the test results of the single rotor wing sail are given in the paper, the type having two rotors with a square sail between is said to be "essentially identical to the tested model". The conclusions were:

- "a combination of the rotor with a wing makes it possible to improve the aerodynamic characteristics of both the isolated rotor and the wing;

- the maximum values of the lift and drag coefficients of the "rotor-wing" for a velocity ratio of 3 exceeded the values of the coefficients obtained for rigging of the "Dynaship" type by a factor of greater than 1.5; when the relative speed of rotation of the rotor is increased to the ratios of 4 to 5 the maximum values are 3 to 4.5 times greater;

- the shape of the wing hardly affects the characteristics of the system;

- the maximum efficiency of the system and its aerodynamic quality are achieved when the rotor is located at the projecting edge of the wing; the relative diameter of boundary (end) plates of the rotor exert a dramatic effect, especially when its extension is reduced;

- the optimum value of the relative diameter of the plates, with allowance for design considerations is $D/d = 1.5$ (D--diameter of plates; d--diameter of rotor);

- the diameters of the rotors operating in concert with the wing can be assumed to be equal to 20 - 25% of the length of the chord of the system for rotor elongation (aspect ratio) = 4 to 5."

This "system makes it possible to engage that rotor which generates higher thrust on a given tack". One obvious flaw in this arrangement is that the drag generated by the active rotor will impose considerable torque on the central support which must be absorbed in some fashion. The two rotors mounted on a pair of yards probably would not need the square fabric sail suspended between them when running before the wind. They could simply be counter-rotated so that the well known turbulent wake of the Magnus effect would form a transverse wall of air between them creating an invisible sail. Sails made of air require no maintenance.

The idea of two rotors mounted on a single, rotatable support is a viable one. It would solve the problem of the windward rotor shadowing the leeward one in a two or four poster configuration when sailing with the wind directly abeam. By adjusting them so the lee rotor is forward of the windward rotor, both could be used at full thrust.

The rotorwing sail concept is not an attractive choice for wind propulsion because its additional complexity is not consistant with the small increase in efficiency.

"Aspirated Cylinders: The Shape of Things to Come", Calypso Log, Special Dispatch, Volume 10, Number 3, Summer 1983.

The aspirated cylinder wind propulsion concept advocated by Captain Jacques-Yves Cousteau is described in detail in Chapter 2 of this report where it was included for its historical importance. The catamaran Moulin à Vent failed an attempted Atlantic crossing powered by the new system.

The aspirated cylinder is a boundary layer control device and is a direct descendant of the Flettner rotor. Although no curves of lift and drag are provided in the Calypso Log article, a maximum lift coefficient of 5 is claimed for the sail. This value is less than half the lift of a rotating cylinder but it is quite possible that the drag coefficient is lower also because the aspirated system probably does not produce the massive turbulent wake as does a rotor. Assuming the drag coefficient of the aspirated cylinder to be the same as that of a static cylinder, that is 0.8, then its lift/drag ratio would be 5/0.8 = 6.25. Very efficient indeed as compared with about 2.75 for a rotor working at the velocity ratio of 4, as indicated by Swanson's curves for a cylinder of infinite length.

The prototype aspirated cylinder is 44 feet high and 4.9125 feet in diameter, giving an aspect ratio of 8.9 and a surface area of 680.3 square feet. Suction is maintained by a 12 hp fan so the ratio of horsepower to cylinder surface area is 0.017 as compared with 0.015 for the rotorship Barbara, thus the power requirements are of the same magnitude.

The new French concept claims an additional advantage in tacking because, unlike the rotor, it need not take the time to stop and reverse its rotation but merely shifts its suction flap. It is difficult to see, however, how the new system has any advantage over a rotorsail when running before the wind. Cousteau rejected the Flettner rotor because "the large cylinders presented about the same wind resistance as the rigging of a traditional ship, which could cause some difficulty in a storm ." Apparently he had not been informed of the hurricane-proof characteristic of the Flettner rotor. No mention is made as to whether an aspirated cylinder experiences the invisible drag phenomenon that the rotor does at very low velocity ratios.

One possible drawback of the aspirated sail is the difficulty in constructing a telescoping or retractable version due to the constraints imposed by the moveable flap. In order to pass beneath bridges, etc, the cylinder would have to be mounted on trunnions and lowered down onto the deck.

The aspirated cylinder is not suitable for naval use where it may be damaged by gunfire. Any loss of suction due to bullet holes or flying fragments would seriously effect its efficiency. A rotor sail, on the other hand, can continue to generate lift even though its shell is dented and badly holed and vibration can be held within tolerable limits.

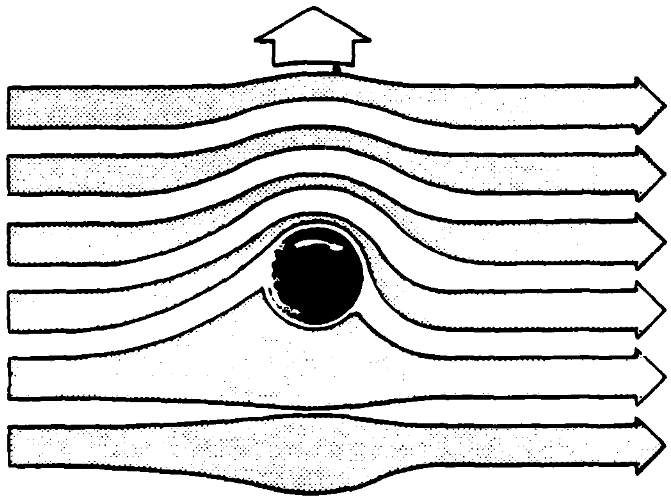
The versatility of the aspirated cylinder is limited in that it would be difficult or even impossible to adapt it for use as a steering or stabilizing device or for high lift propeller blades although it could conceivably serve as prime mover in some sort of wind powered generator. The Calypso Log informs us that the French government has agreed to outfit further test vessels. By the end of 1984, at least 3 private commercial ships will be at sea using cylindrical sails.

Cousteau's famous ability to gain public attention will be beneficial to any future Magnus effect development program by lending credibility to the idea of cylindrical sails. The aspirated cylinder, however, is not what the Navy needs for auxiliary wind propulsion and other uses.

MAGNUS EFFECT

–

AN OVERVIEW OF ITS PAST AND FUTURE PRACTICAL APPLICATIONS



VOLUME II

(APPENDIX D)

PATENT REVIEW AND ILLUSTRATIONS

PREPARED BY

THE BORG/LUTHER GROUP

FOR

NAVAL SEA SYSTEMS COMMAND
DEPARTMENT OF THE NAVY
WASHINGTON, DC 20362

CONTRACT #N00024-83-C-5350

"THE MAGNUS EFFECT - AN OVERVIEW OF ITS PAST AND FUTURE PRACTICAL APPLICATIONS"

VOLUME II

(APPENDIX D)

PATENT REVIEW AND ILLUSTRATIONS

PREPARED BY THE BORG/LUTHER GROUP
FOR
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DEPARTMENT OF THE NAVY
WASHINGTON, DC 20362

CONTRACT #N00024-83-C-5350

TABLE OF CONTENTS

FORWARD

In writing Volume II, we felt we could contribute to the state-of-the-art Magnus effect by organizing the patents into categories as a form of a planning network. Each patent is separately described and in its description are provided the considerations, techniques and methods necessary for its execution.

In complement to the discussions of the patents, relevent literatature is evaluated.

The importance of patents and available information in determining continued efforts in Magnus effect designs is emphasized.

Together with Volume I, this report is a record of the history and state-of-the-art in Magnus effect that can form the technological base for further development in this subject area.

INTRODUCTION

Technology that is patented is protected by law and such patents often control development in that area. The patent confers exclusionary rights to the patentee for the use, manufacture and sale of the invention, initially for 17 years. (The patent may be extended for an additional 17 years.) Once the exclusive rights expire, the invention becomes public domain.

Earlier Magnus effect designs are public domain, while later Magnus effect designs are still protected. Because Magnus effect designs are evolving, it is imperative that patents be researched to ascertain the status prior to developmental programs.

This section describes the basic concept of each patent, its functional elements, capabilities, limitations and restrictions, and includes detailed illustrations.

The patents are discussed chronologically within the following categories: ship propulsion, ship steering, ship stability, energy converters, and aircraft.

SHIP PROPULSION

C.J. LOW, PROPELLER, U.S. PATENT 1,041,825, ISSUED OCTOBER 22, 1912

The Low propeller predates the Flettner patent and it is quite conceivable that Low discovered the principal without learning of Flettner's experiments. Although the device was intended to lift an airship, it also includes watercraft propulsion.

The propeller consists of hourglass shaped blades or rotors, each composed of two external hemispheres (item 6) and two internal hemispheres (item 18). The purpose of the internal hemispheres is not clearly explained nor does the gear arrangement account for the reversal of the direction of thrust. Regardless of the directon of shaft rotation, the orientation of the component of lift will always be upward or forward; thus, it would not be suitable for use on vessels.

ASSESSMENT: The Low propeller probably worked but it is difficult to assess its efficiency. The concept of hemispherical rotors is of doubtful value in modern marine applications.

416-4

Examiner

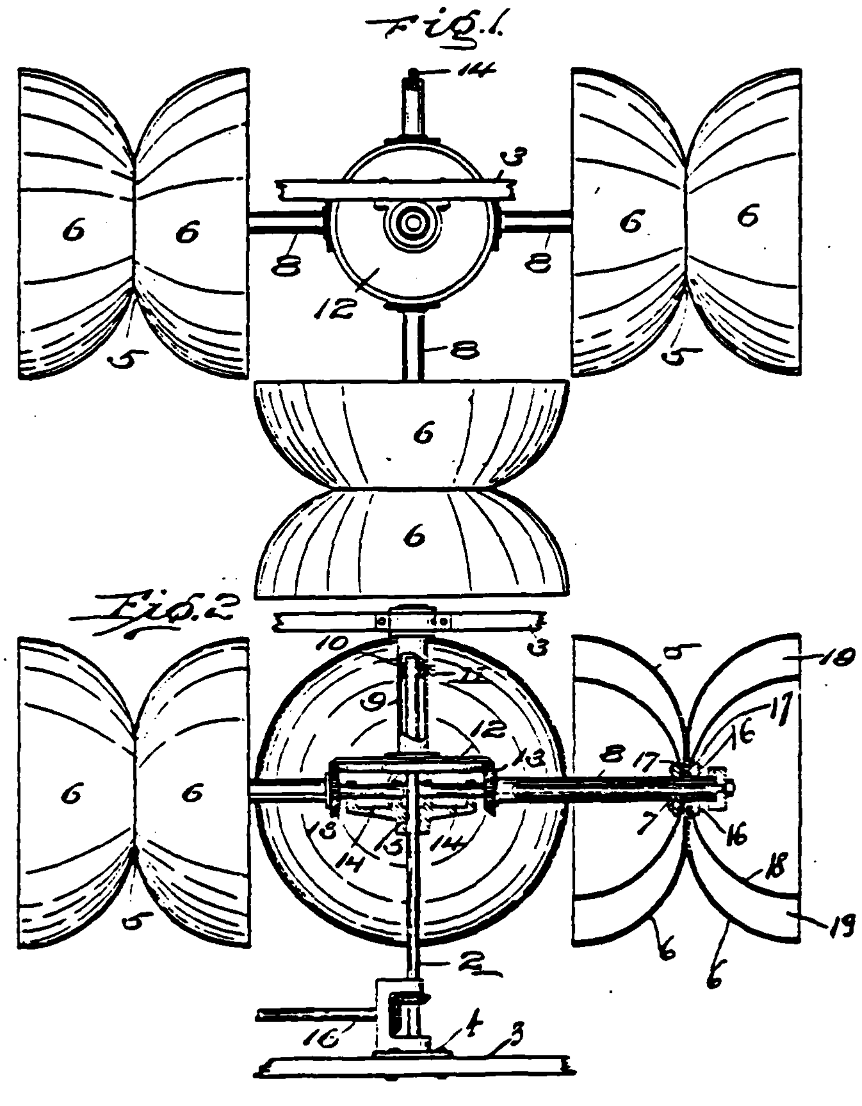
C. J. LOW.

PROPELLER.

APPLICATION FILED FEB. 14, 1911.

1,041,825.

Patented Oct. 22, 1912.



WITNESSES
R. R. Duffie
N. E. Garner

INVENTOR
Chas. J. Low
BY John A. Duffie
ATTORNEY

H. FRITZEL, GUIDE BODY FOR REACTION ROTORS, U.S. PATENT 1,640,891, ISSUED AUGUST 30, 1927

The patent states that the guide body is to be used with Flettner rotors, then called "reaction-rotors". Interestingly, Flettner's patent was not awarded in the U.S. until nearly a year later.

The guide body consists of biconcave surfaces joining in a knife edge whose purpose is "to avoid damming up and formation of eddies." The efficiency of the rotor is further enhanced by suction slots (item M) arranged longitudinally along the face of the guide. The inventor states that guide orientation devices would not be required if the flow originates from only one direction.

- Figure 1 shows a section through a conventional rotor.

- Figure 2 is a section through a rotor of the same diameter fitted with guide bodies (items g and f).

- In Figure 3, the dimension (item h) is the increase in effective area of the rotor. This area is approximately doubled by the use of the guides. This means that the rotor's lifting force can be increased by 100%.

- Figures 5 and 6 show mechanical arrangements for adjusting the guide bodies, the suction slots, and the pump.

ASSESSMENT: The Fritzel patent is quite sophisticated and indicates that some experimentation was performed. The concept merits further investigation. It shows a method for increasing rotor lift without increasing the aspect ratio; thus, improving performance without compromising structural considerations.

Aug. 30, 1927. 1,640,891

H. FRITZEL

GUIDE BODY FOR REACTION MOTORS

Filed Sept. 23, 1925 2 Sheets-Sheet 1

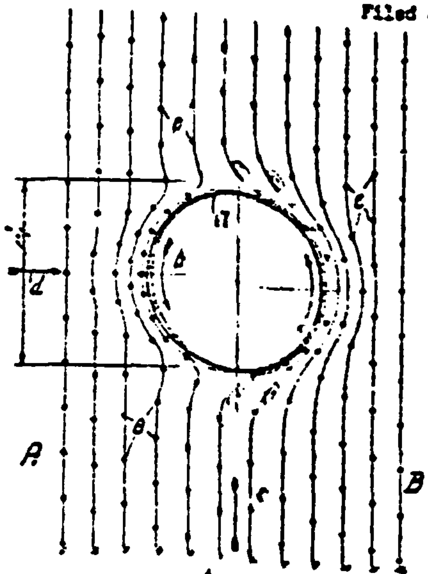


Fig. 1

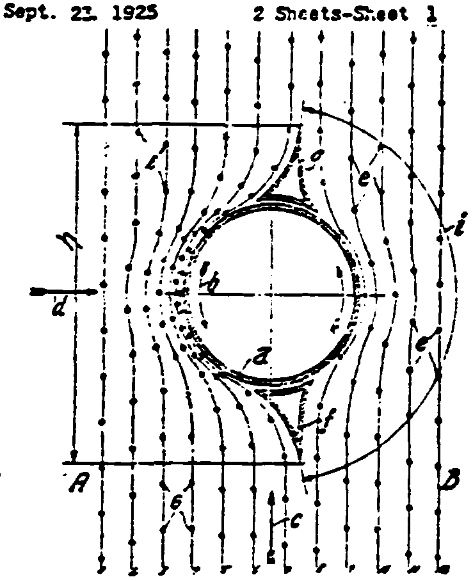


Fig. 2

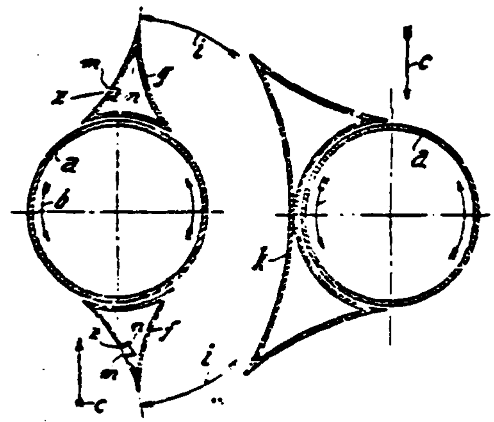


Fig. 4 Fig. 3

Inventor:

Hugo Fritzel.

Aug. 30, 1927.

H. FRITZEL

1,640,891

GUIDE BODY FOR REACTION ROTORS

Filed Sept. 23, 1925

2 Sheets-Sheet 2

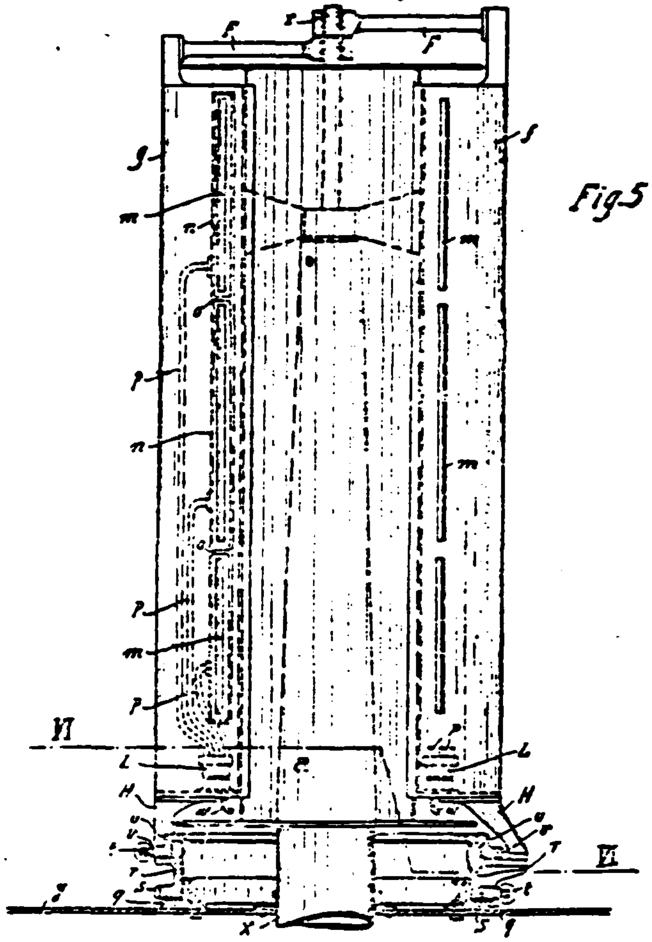


Fig. 5

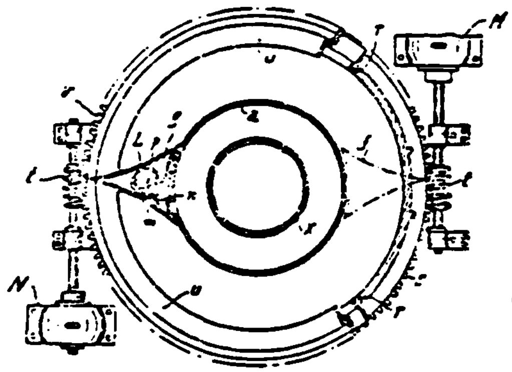


Fig. 6

Inventor:
Hugo Fritzel

A. FLETTNER, ARRANGEMENT FOR EXCHANGING ENERGY BETWEEN A CURRENT AND A BODY THEREIN, U.S. PATENT 1,674,169, ISSUED JUNE 19, 1928. APPLICATION FILED IN GERMANY JULY, 1923.

Anton Flettner's basic patent was intended to cover every possible Magnus effect sail configuration. Magnus effect propellers are mentioned in the text, although none are shown in the drawings.

- Figures 1 through 20 illustrate many Magnus effect sail configurations.
- Figures 10, 11, 18, 19, 20, 21, 22 and 23 show rotors having various profiles (including the famous cylinder).
- Figures 6, 7, 8, 9, 12 and 13 are cylindrical sails with different types of airfoil shaped fairings.
- Figures 1, 2, 3, 4, 5, 14 and 15 are ribbon type sails driven by rollers. (Figure 2 shows how a Flettner fin or trim tab could used to sheet the sail.)
- Figure 24 is a cutaway view of a rotor sail showing a means for driving the upper portion at a different speed. This topsail would take advantage of higher wind velocities aloft.
- Figures 25 and 26 illustrate internal structural arrangements for rotor sails.
- Figures 27 and 28 are windmills having adjustable legs and fitted with trim tabs. Note that the blades are tipped back at a small angle.

The text of the patent points out that it may be desireable to drive the end disks at a different velocity than the cylindrical portion of the rotor. The purpose of this arrangement would be to draw the fluid medium away from the center of the rotor and provide a uniform load distribution along its length.

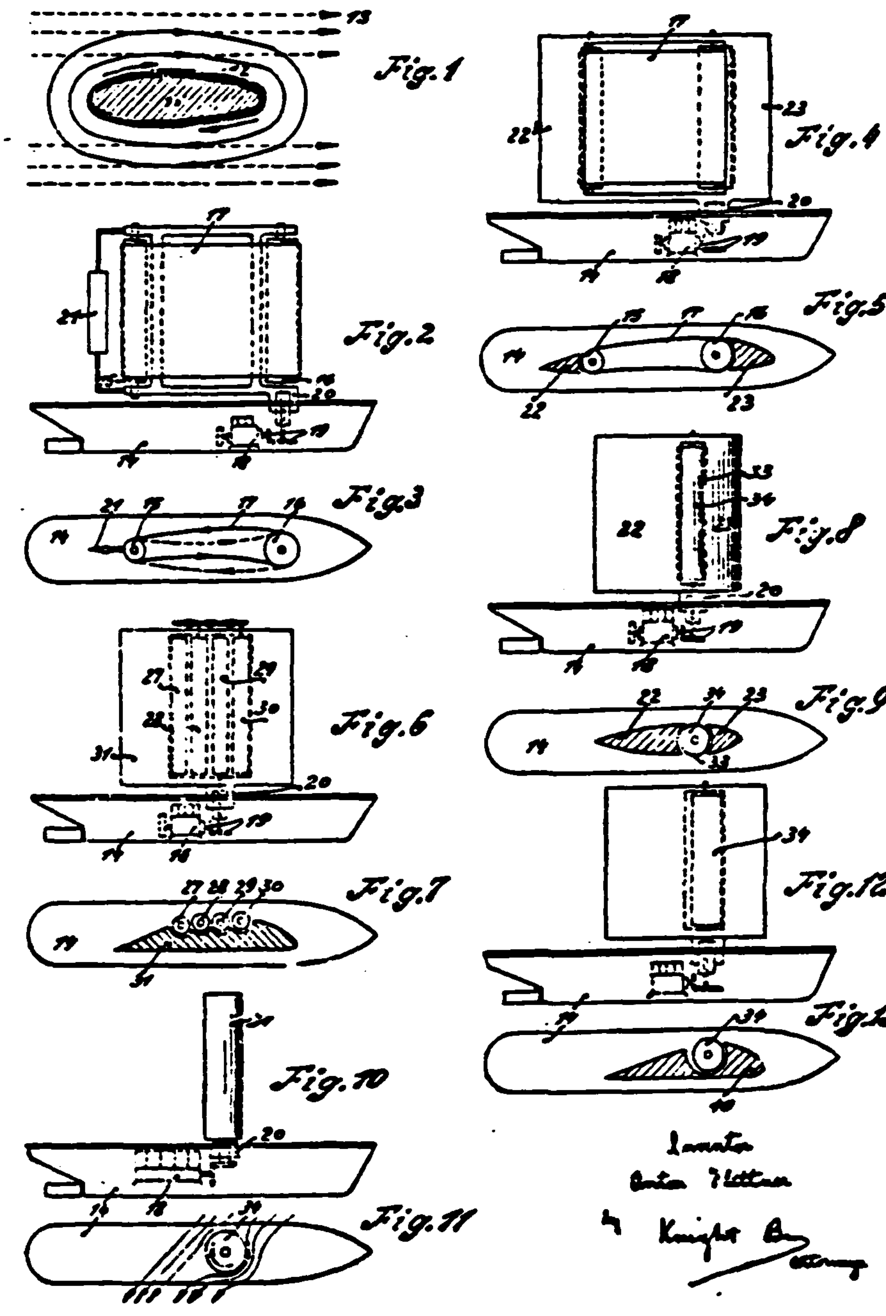
ASSESSMENT: This concept may have some merit and should be checked out experimentally. Both the rotor sails and windmills covered by this patent are of potential value in marine operations.

June 19, 1928. 1,674,169

A. FLETTNER

ARRANGEMENT FOR EXCHANGING ENERGY BETWEEN A CURRENT AND A BODY THEREIN

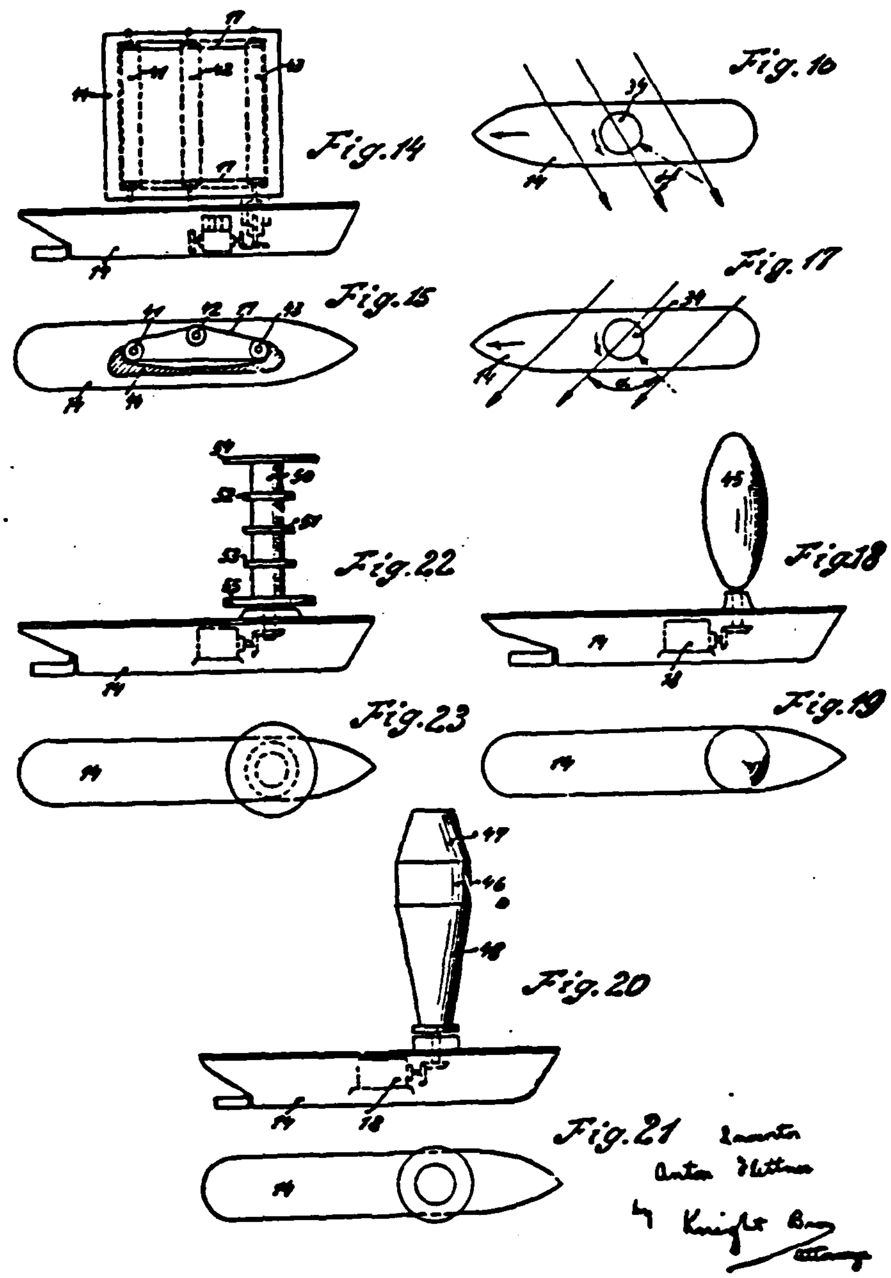
Filed July 18, 1924 4 Sheets-Sheet 1



June 19, 1928. A. FLETTNER 1,674,169

ARRANGEMENT FOR EXCHANGING ENERGY BETWEEN A CURRENT AND A BODY THEREIN

Filed July 18, 1924 4 Sheets-Sheet 2



June 19, 1928. 1,674,169

A. FLETTNER

ARRANGEMENT FOR EXCHANGING ENERGY BETWEEN A CURRENT AND A BODY THEREIN

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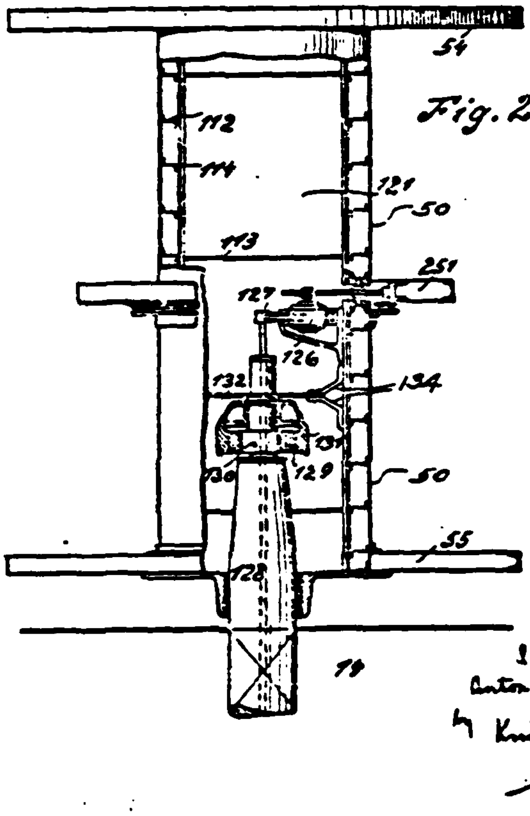


Fig. 24

Inventor
Anton Flettner
by Knight Bros
Attys

June 19, 1928. 1,674,169

A. FLETTNER

ARRANGEMENT FOR EXCHANGING ENERGY BETWEEN A CURRENT AND A BODY THEREIN

Filed July 18, 1924 4 Sheets-Sheet 4

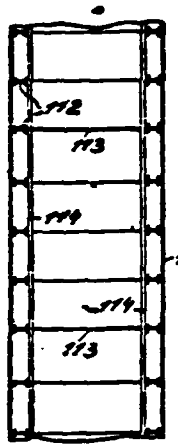


Fig. 25

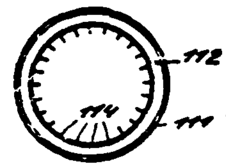


Fig. 26

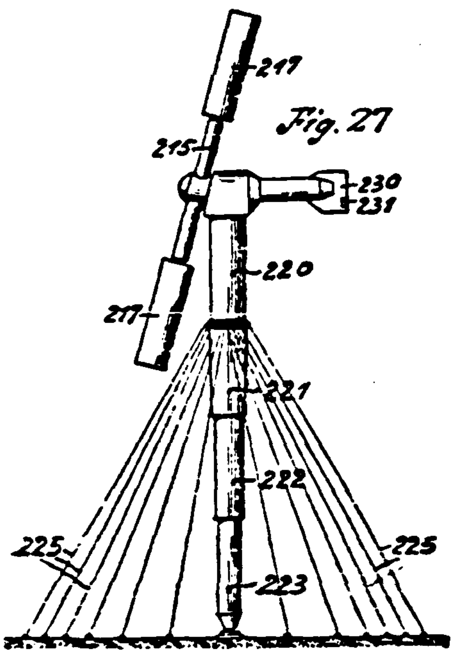


Fig. 27

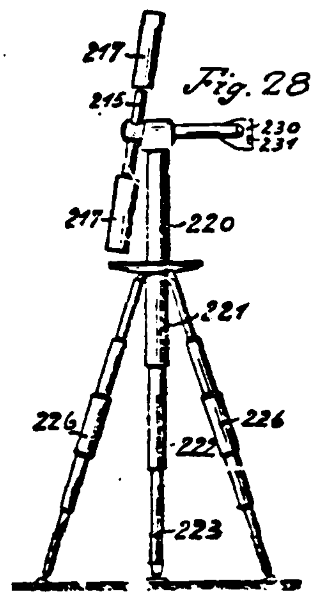


Fig. 28

Inventor
Anton Flettner
by Knight Bros
Attorneys

P.J. JENSEN, PROPULSEUR POUR AIR OU POUR EAU (PROPELLER FOR AIR OR FOR WATER), FRENCH PATENT (659,443) ISSUED TO A RESIDENT OF NORWAY JUNE 28, 1929

- The Jensen propeller shown in Figure 1 has a pair of rotors driven by bevel gears (item d) and a ring gear (item f) which are fixed to the hull of the ship. As the propeller shaft turns, the rotors are caused to spin, thus generating lifting force. This arrangement would be a pusher-type propeller regardless of the direction of shaft rotation.

- Figure 2 is a similar propeller fitted with a rotating fairing and idler gears. The idlers enable the propeller to be a tractor or puller type as though for use on conventional aircraft.

ASSESSMENT: Neither arrangement provides for the thrust reversal feature that is desirable for use on a vessel. Aside from this, the propeller would have performed well and very possibly would have been more efficient than contemporary screw types.

416-4 - FRANCE #659,443

154M

N° 659.443 M. Jensen Pl. unique

(6-1929)

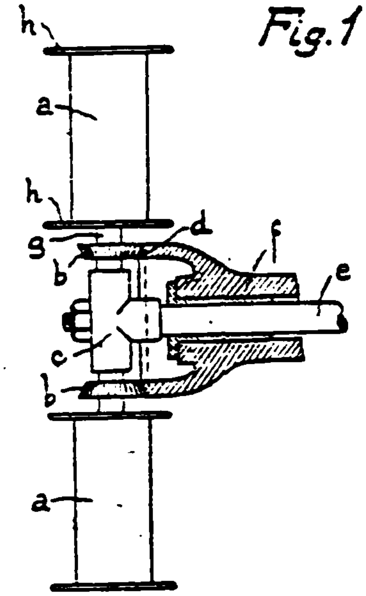


Fig. 1

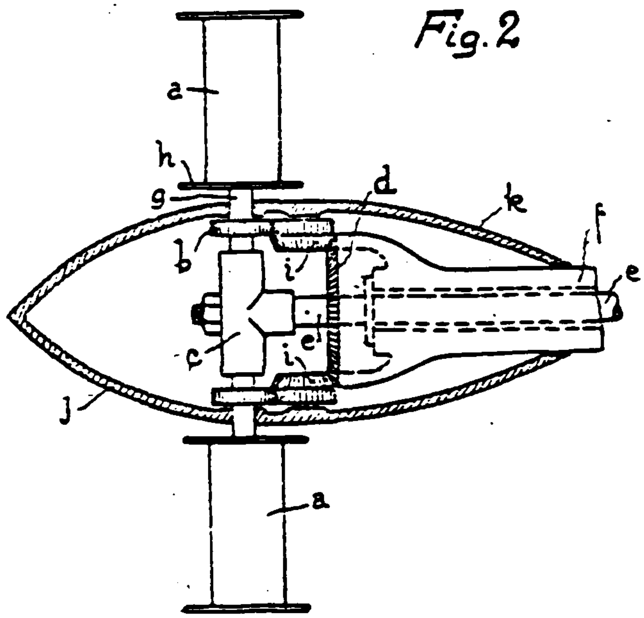


Fig. 2

J.G.A. RYDELL, WIND MOTOR, U.S. PATENT 2,596,726 ISSUED MAY 13, 1952

Rydell's Wind Motor combines the Flettner rotor with the Savonius autorotor and adds a telescoping feature for adjusting the height of the sail. The mechanism for adjusting the height of the rotor is a complex system of threaded rods, worm gears, and planetary gear arrangements.

The Wind Motor can be used in four distinct modes:

1) It can propel the vessel with a power driven Flettner style rotor (motor driven).

2) It can propel the vessel by shifting the halves of the cylinder to a Savonius rotor configuration, adjustable for either port or starboard tack. While the Savonius rotor is less efficient than a cylindrical rotor, it can be used during high velocity wind conditions; thus saving fuel which is needed to drive the cylindrical rotor.

3) In suitable conditions, it can be used as a vertical axis windmill to generate electrical energy.

4) It can be lowered by means of the telescoping system to reduce windage while the vessel is navigating under power alone or to allow the vessel to pass under obstructions such as bridges.

   - Figure 1 shows a transverse section through a ship with the rotor extended to its full height. A mast or shaft extends through the assembly and is supported by side stays attached to spider bars at the masthead.

   - Figures 3 and 4 illustrate the shift of the half cylinders into a Savonius autorotor.

   - Figures 5, 6 and 7 relate to the shift controllers and rotor drive.

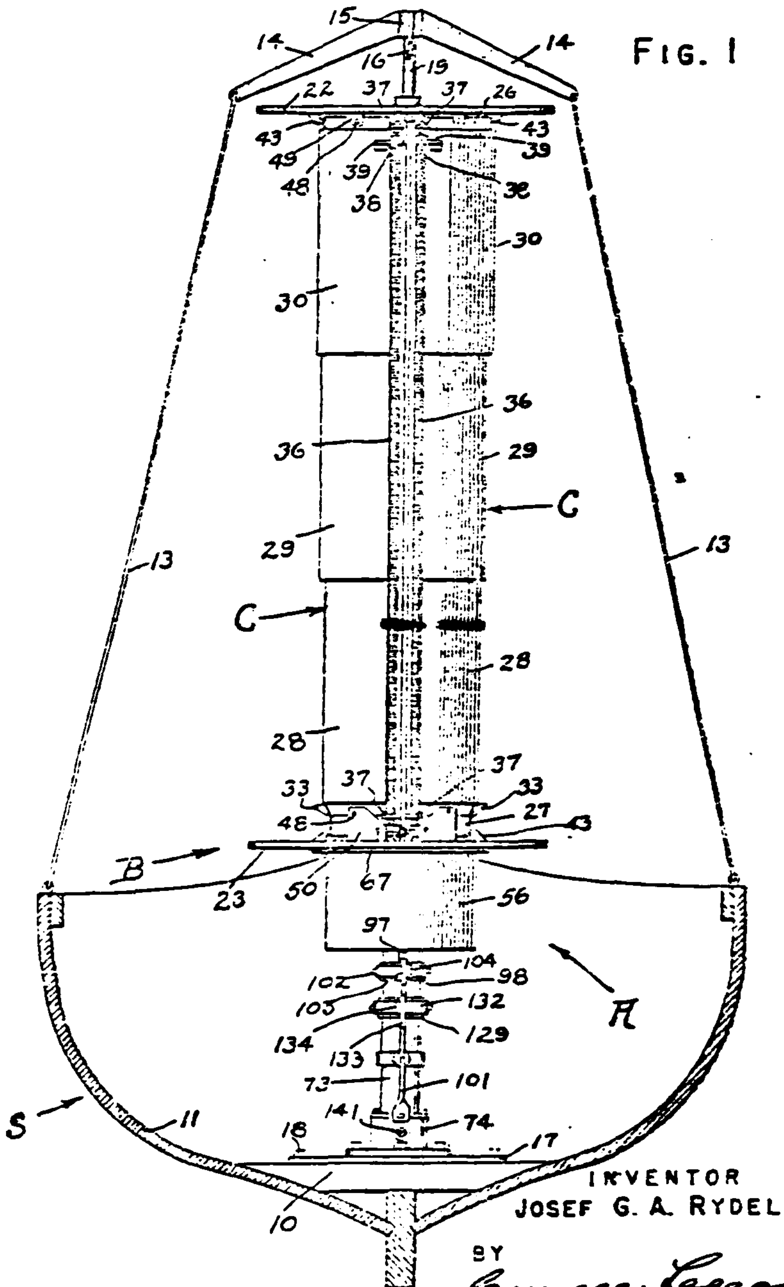
ASSESSMENT: The Rydell Wind motor is an ingenius design but would doubtless be very expensive to construct. It should definitely be considered as a possible auxiliary propulsion and energy converter system by the Navy, but only if contemporary devices such as electrically driven ball screws could be adapted to simplify the shifting arrangements and thereby reduce the initial cost. The idea is a good one and solves many of the shortcomings of rotor sails.

May 13, 1952 J. G. A. RYDELL 2,596,726

WIND MOTOR

Filed May 26, 1948 6 Sheets-Sheet 1

FIG. 1



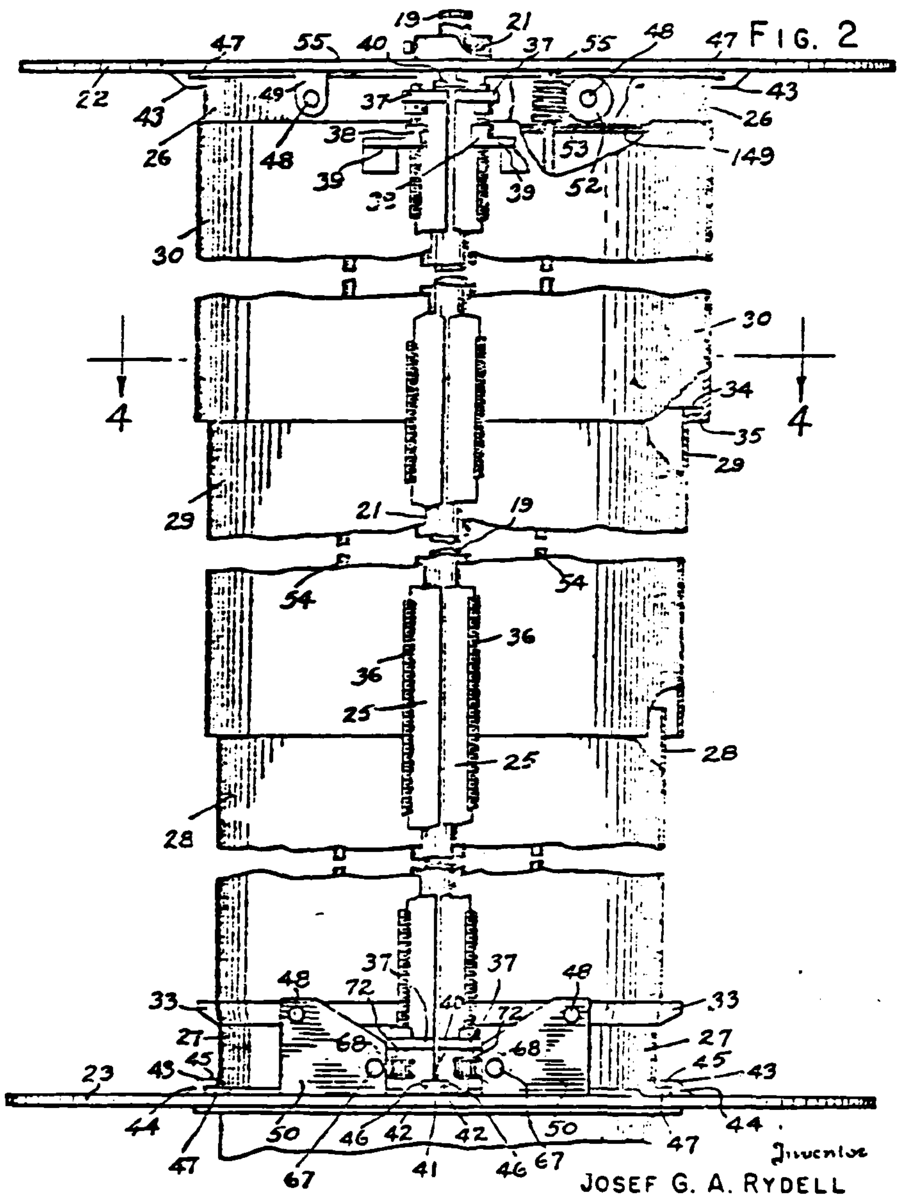
INVENTOR
JOSEF G. A. RYDELL

BY
Carroll + Lagaard
ATTORNEYS

WIND MOTOR

Filed May 26, 1948 6 Sheets-Sheet 2

FIG. 2



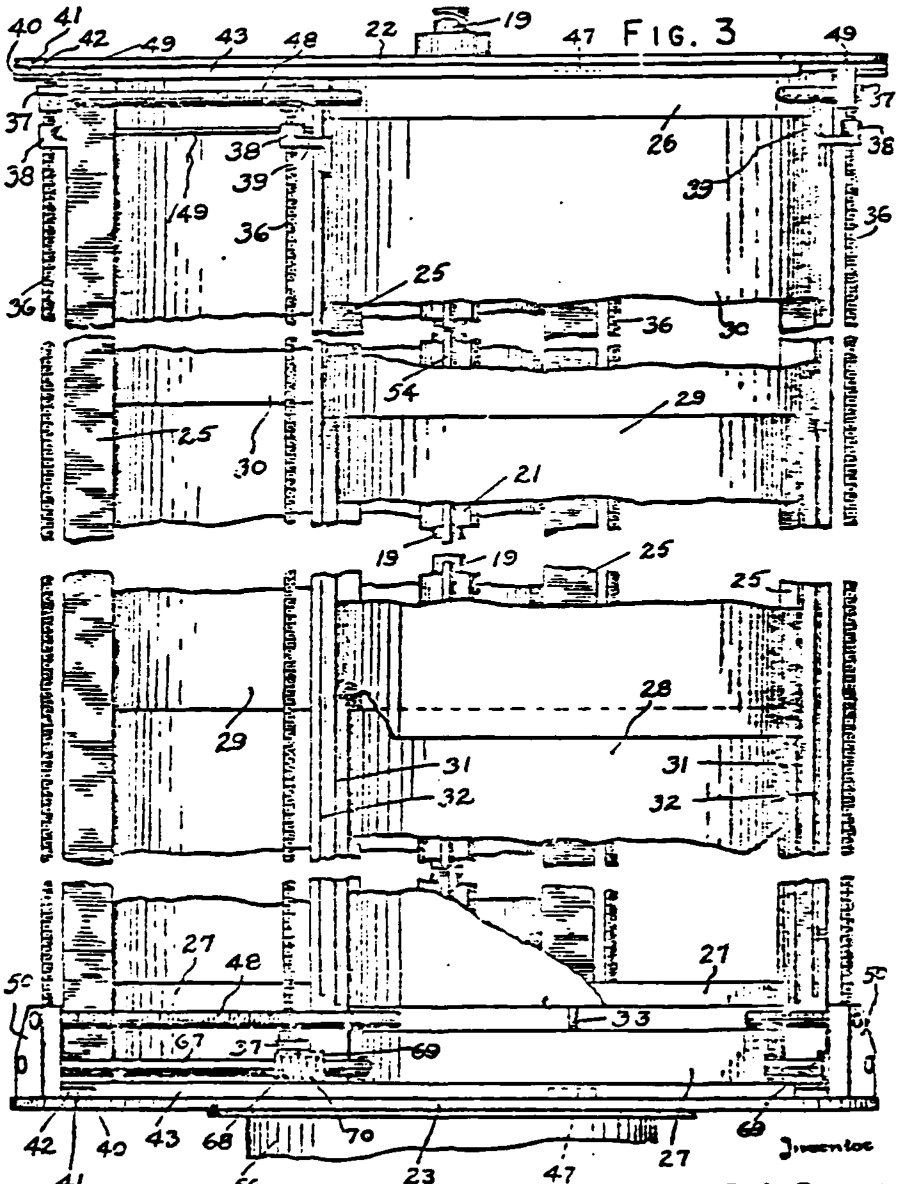
Inventor
JOSEF G. A. RYDELL

By Caswell + Lagaard
Attorneys

May 13, 1952 J. G. A. RYDELL 2,596,726

WIND MOTOR

Filed May 26, 1948 6 Sheets-Sheet 3



Inventor
JOSEF G. A. RYDELL

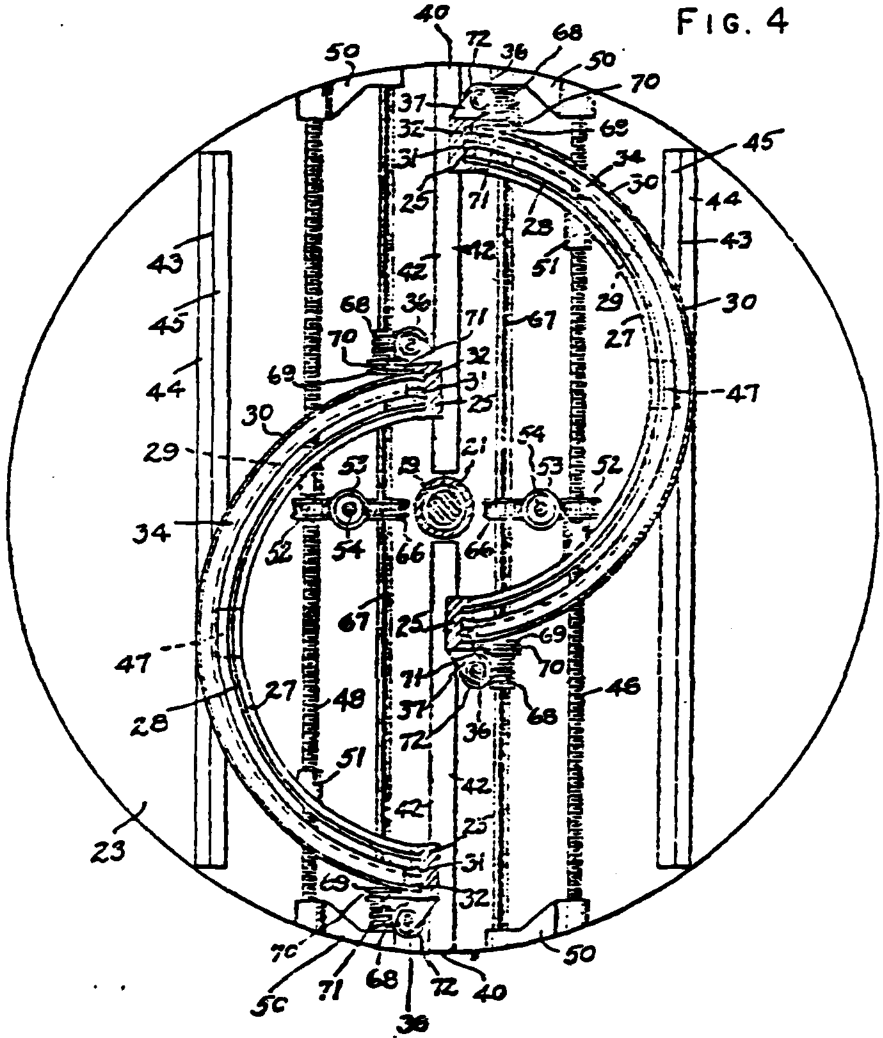
By Cranwell & Lagaard
Attorneys

May 13, 1952 J. G. A. RYDELL 2,596,726

WIND MOTOR

Filed May 26, 1948 6 Sheets-Sheet 4

FIG. 4



Inventor
JOSEF G. A. RYDELL

By Carroll & Lagaard
Attorneys

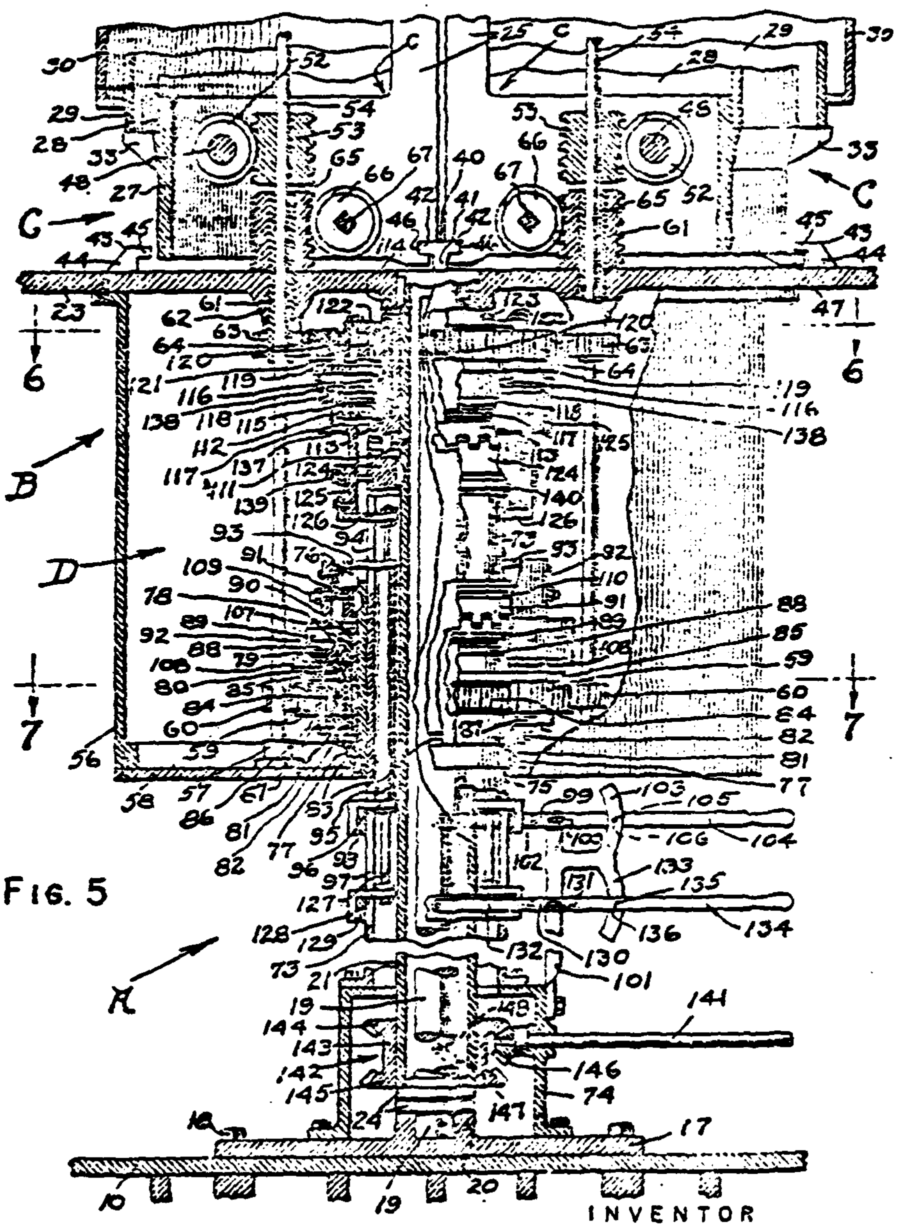


FIG. 5

INVENTOR
JOSEF G. A. RYDELL
BY
Caswell + Lagaard
ATTORNEYS

FIG. 6

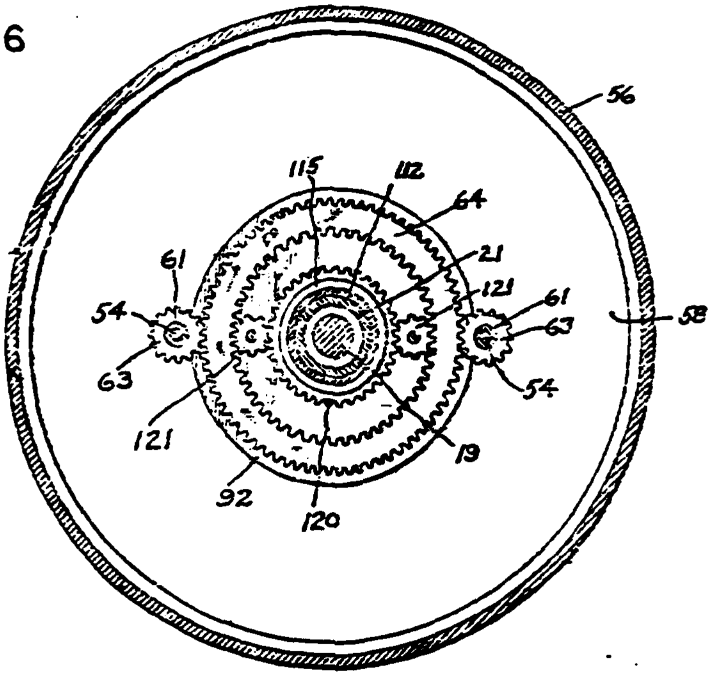
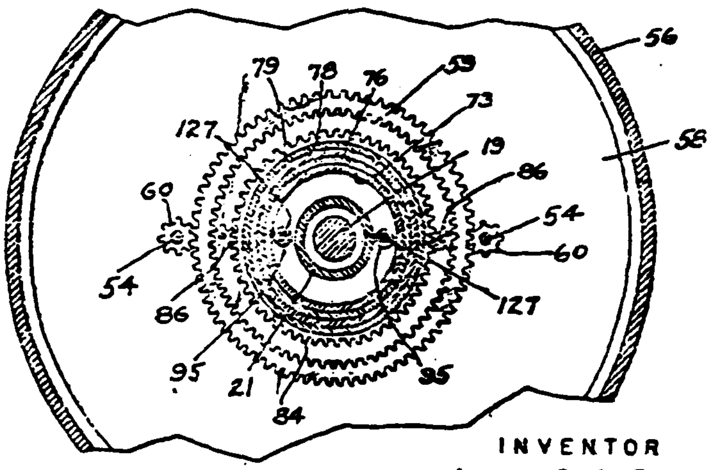


FIG. 7



INVENTOR
JOSEF G. A. RYDELL
BY
Caswell & Lagaard
ATTORNEYS

W. FORK, THRUST GENERATING DEVICE, U.S. PATENT 4,225,286 ISSUED SEPTEMBER 30, 1980. PATENT ISSUED BY FEDERAL REPUBLIC OF GERMANY JANUARY 19, 1977. ASSIGNED TO J.M. VOITH GmbH, HEIDENHEIM, FEDERAL REPUBLIC OF GERMANY

The Fork thrust genreating device is a Voith Schneider cycloid propeller whereby the original flat vanes have been replaced with Magnus effect rotors. The patent is assigned to the firm that constructs those propellers.

In addition to increased propulsive efficiency, the inventor claims that the rotors are stronger than vanes, less susceptible to damage from grounding or debris in the water, and less prone to clogging by aquatic plants.

One embodiment of the invention consists in having the rotary cylinders drivable in each case through a shaft turning with the hub by means of a friction wheel fixed on the shaft and running on a stationary plate. The orbit diameter and the position of the circular orbit made by the friction wheel on the plate is determined by means of a linkage connected to a control bar. The location and adjustment of the linkage is effected by the same device used to adjust vanes on the Voith Schneider propeller.

Other rotor drive options are an hydraulic or electric motor, and a toothed rack and pinion arrangement.

- Figure 1 illustrates the operating principle of the invention.
  It shows how each cylinder must reverse its direction of rotation once during one revolution of the assembly. In other words, the rotational speed becomes zero twice and reaches a maximum twice. The magnitude of the thrust is determined by the speed of rotation and is fixed by the phase relationship of the beginning or end of a direction of rotation.

- Figure 2 shows the sinusoidal curve for the angular speed of a rotary cylinder.

- Figures 3 and 4 relate to the friction wheel rotor drive option.

- Figures 5, 6 and 7 illustrate various positions of the friction wheel.

- Figure 8 shows a mechanical-hydraulic drive option.

- Figure 9 is the rack and pinion drive.

- Figure 10 illustrates a ship fitted with the device

- Figure 11 is a view of the entire assembly.

ASSESSMENT: While the Fork invention is practical, it could be improved. First, the addition of end disks on the cylinders would improve the thrust. Second, the rapid reversal of cylinder rotation could be difficult to achieve by any means.

In spite of these minor criticisms, the Magnus effect Voith Schneider propeller looks promising. An effort should be made to contact the German firm to learn how work is progressing.

United States Patent [19]

Fork

[11] **4,225,286**

[45] **Sep. 30, 1980**

[54] **THRUST GENERATING DEVICE**

[75] Inventor: **Werner Fork**, Heidenheim, Fed. Rep. of Germany

[73] Assignee: **J. M. Voith GmbH**, Heidenheim, Fed. Rep. of Germany

[21] Appl. No.: **869,895**

[22] Filed: **Jan. 16, 1978**

[30] **Foreign Application Priority Data**

Jan. 19, 1977 [DE] Fed. Rep. of Germany 2701914

[51] **Int. Cl.**[3] **F01D 1/36; F03B 5/00**

[52] **U.S. Cl.** **416/4**; 416/108; 416/111

[58] **Field of Search** .... 416/111 A, 108 A, 4; 115/52; 244/10, 21, 39

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Primary Examiner—Everette A. Powell, Jr.
Assistant Examiner—A. N. Trausch, III
Attorney, Agent, or Firm—Edwin E. Greigg

[57] **ABSTRACT**

A device for generating a thrust in a liquid utilizing rotating cylinders. The cylinders are mounted on a rotatable hub and rotate about their own axes relative to the hub. The relative rotation follows, preferably, a sinusoidal path for producing the thrust, and in particular, each cylinder undergoes a reversal in its direction of rotation after each half rotation of the hub. A common control bar is included which is connected to each cylinder and eccentrically with respect to the axis of rotation of the hub so that the points of reversal and the direction of thrust can be adjusted.

2 Claims, 11 Drawing Figures

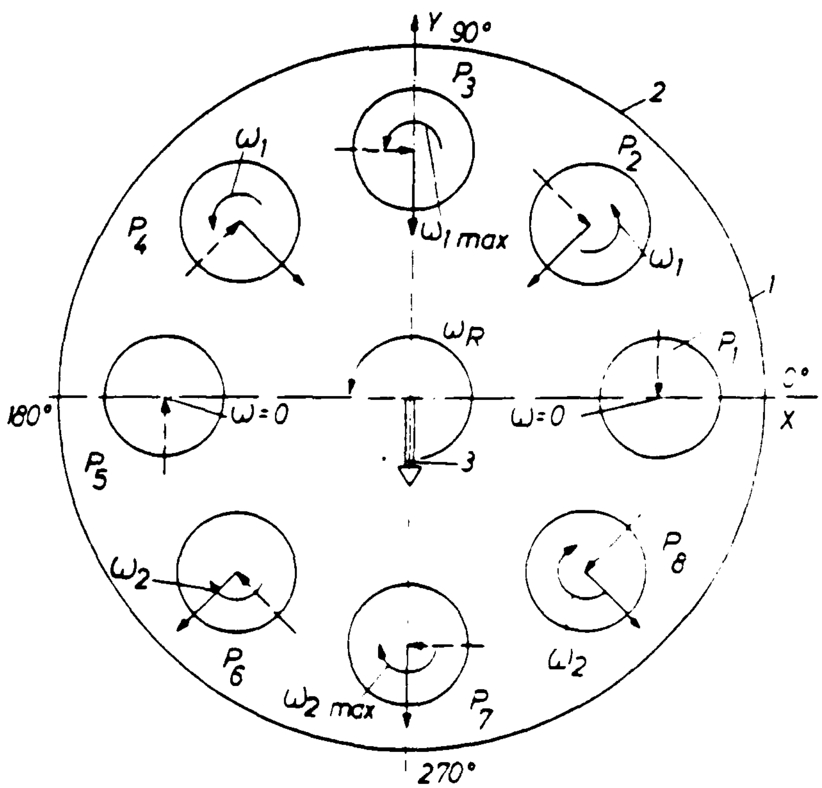


Fig. 1

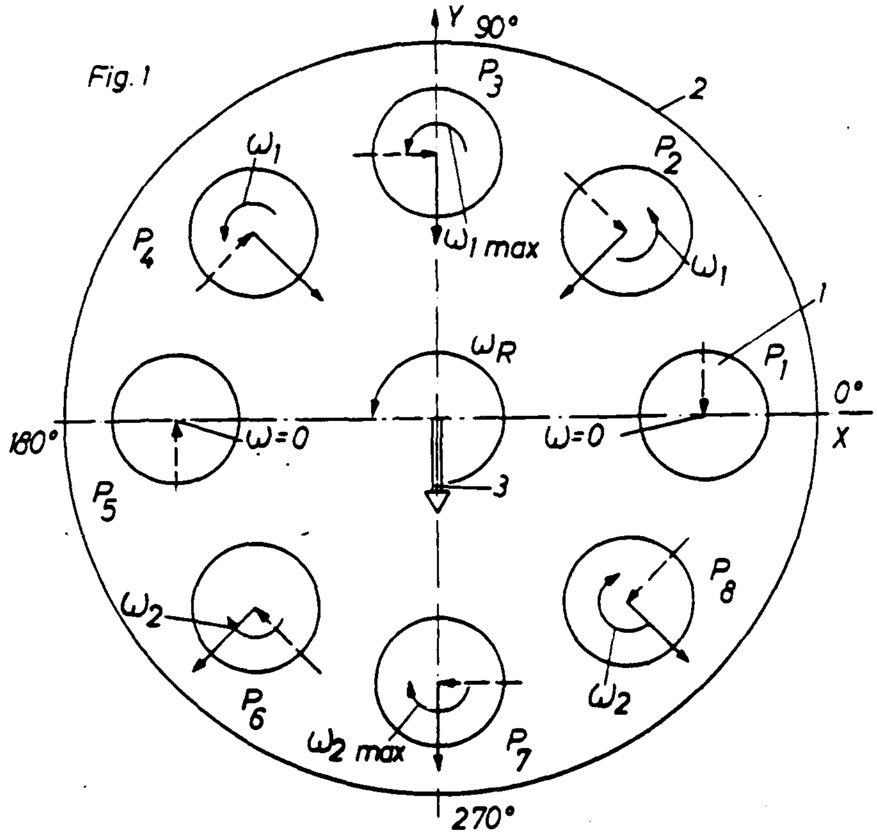
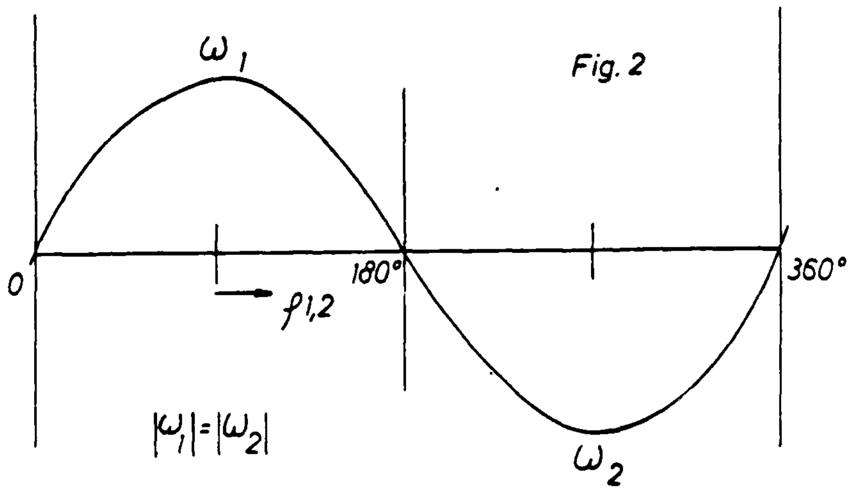

Y
90°
P3
2
ω1
P2
P4
ω1 max
ω1
1
ωR
P1
0°
180°
ω=0
ω=0
X
3
P5
P8
ω2
P6
ω2
ω2 max
P7
270°

Fig. 2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0
180°
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φ1,2
|ω1|=|ω2|
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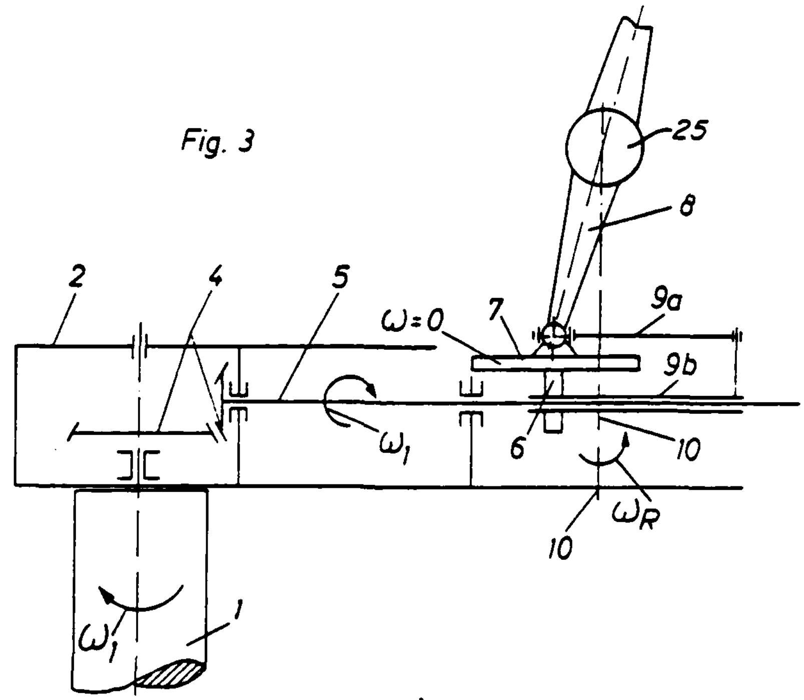
Fig. 3



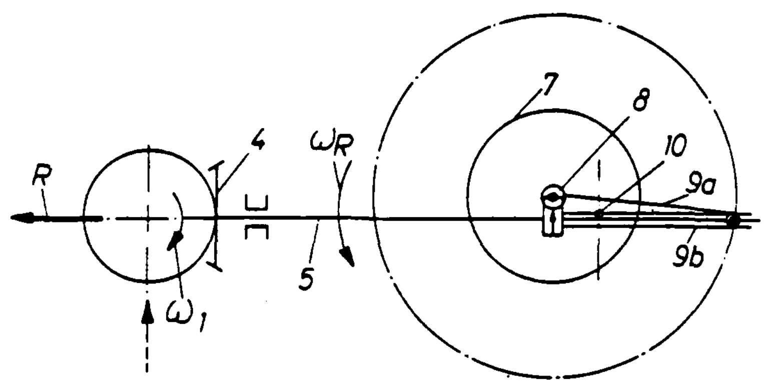


Fig. 4

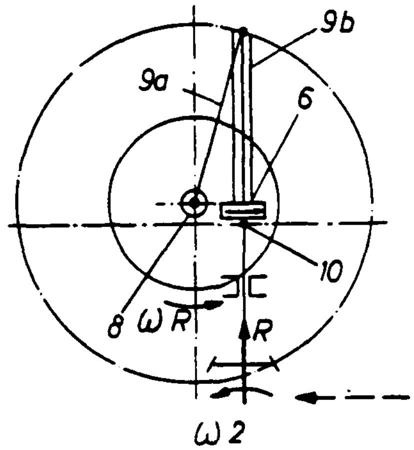


Fig. 5

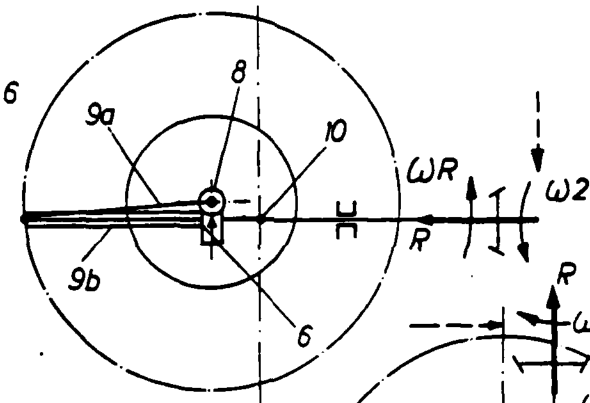


Fig. 6

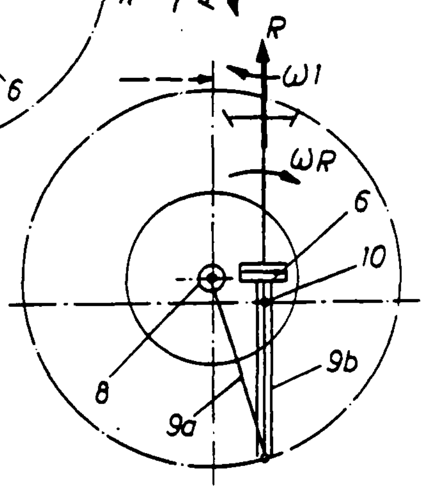


Fig. 7

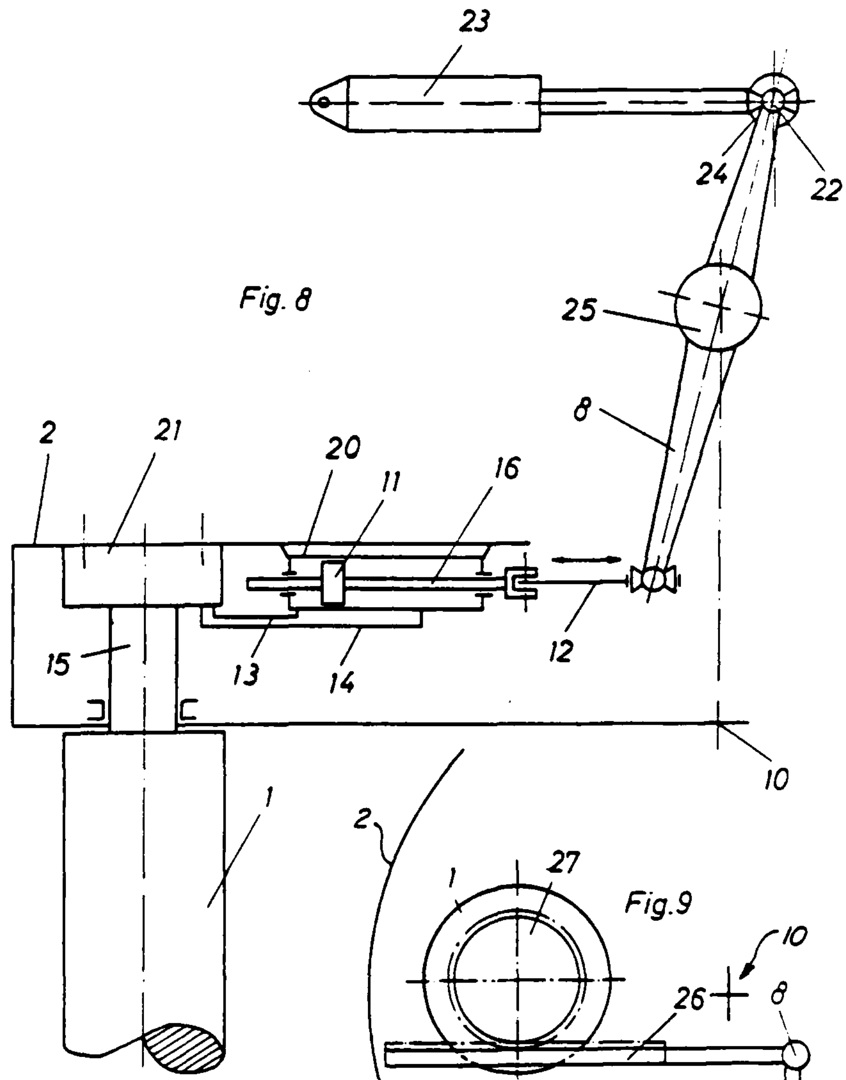


Fig. 8

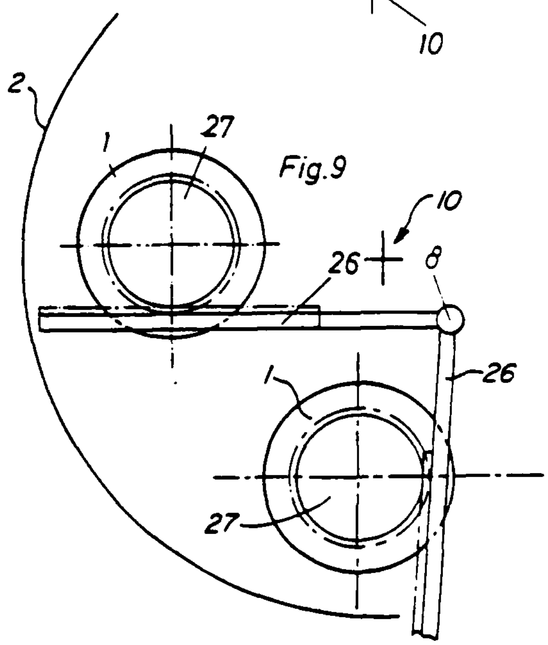


Fig. 9

Fig. 10

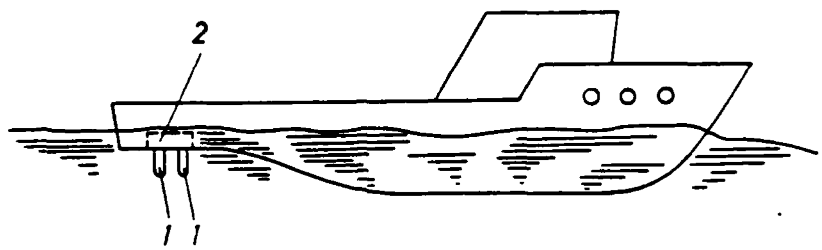
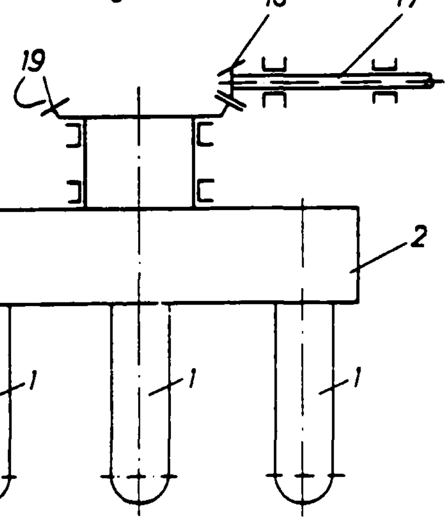


Fig. 11

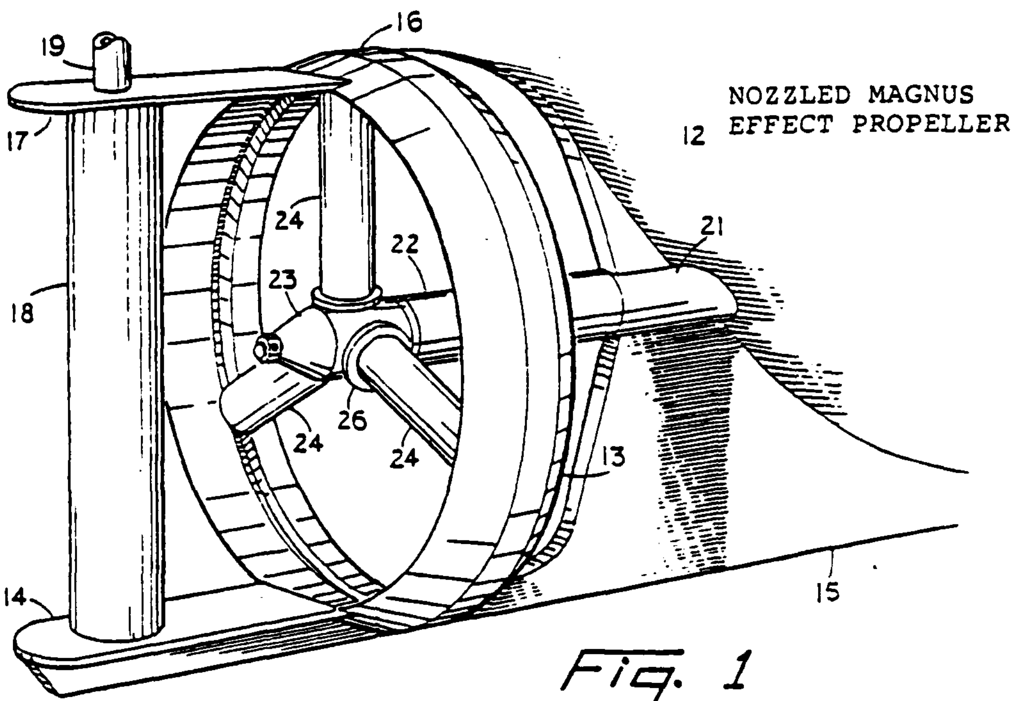


J.L. BORG, NOZZELED MAGNUS EFFECT PROPELLER, U.S. PATENT PENDING, FILED NOVEMBER 30, 1981

The Borg invention consists of a horizontal axis propeller having two or more radially positioned rotors in place of conventional flat blades.

This invention is the only reversible horizontal shaft Magnus effect propeller. (The W. Fork cycloidal propeller is reversible but it is a vertical shaft type.) The propeller assembly is surrounded by a ring similar to a Kort nozzle. The rotors are impelled by friction wheels located at their tips running against the surface of a groove or race which is recessed into the inner surface of the nozzle. When the rotor tips impinge against the forward edge of the groove, the vessel will be propelled in the forward direction. Reversing is accomplished by shifting the propeller assembly a short distance aft so that the rotor tip friction wheel will impinge upon the aft face of the drive ring groove. The shifting is performed by means of a splined coupling in the propeller tailshaft, and a collar and thrust bearing that may be moved forward or aft by mechanical means. Aside from the advantage of developing more pounds of thrust per shaft horsepower, the nozzled Magnus effect propeller has other unique features. Mounted within a ring, end disks are not required at the outboard tips of the rotary blades. (These disks generate hydrodynamic drag and therefore require a significant amount of power to overcome surface friction in a fluid medium.) The reversible rotor drive arrangement eliminates the need for reverse gear at the main engine.

ASSESSMENT: The Borg propeller lends itself to retrofitting upon existing vessels. The nozzled Magnus effect propeller could be of considerable value on certain types of vessels because of its fuel saving potential and its ability to develop virtually as much thrust in the astern mode as when steaming forward.


19
16
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NOZZLED MAGNUS
EFFECT PROPELLER
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Fig. 1

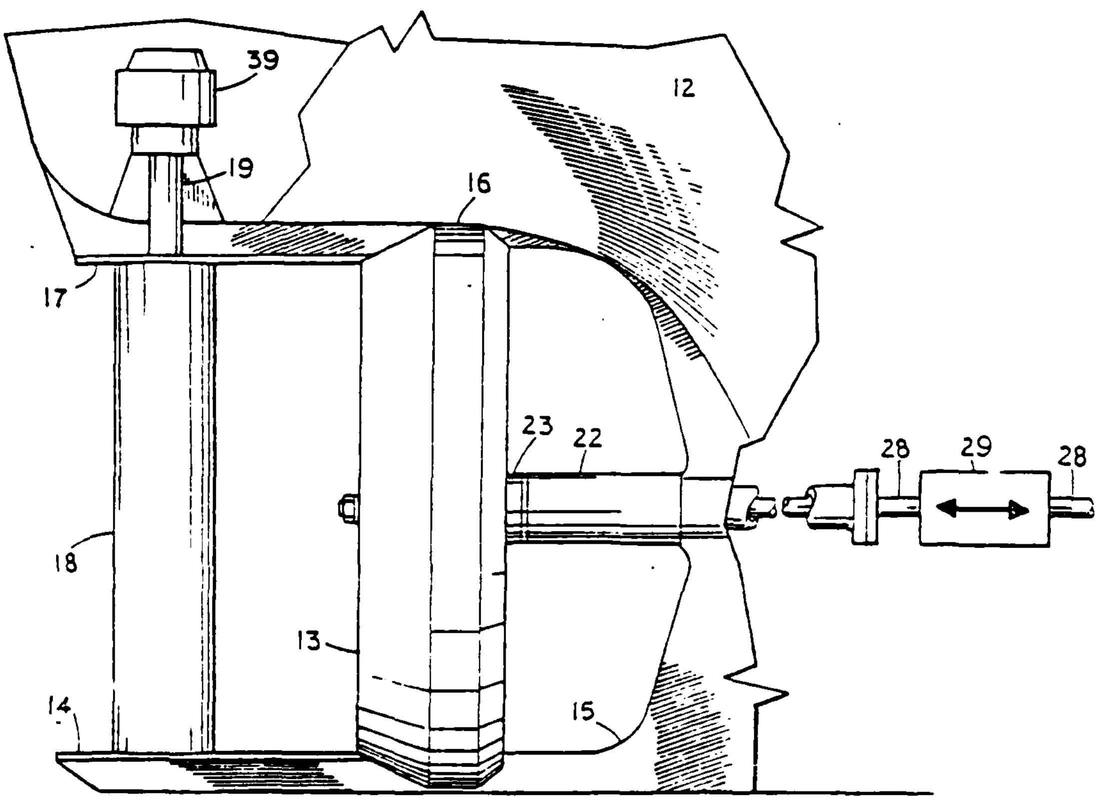
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Fig. 2

NOZZLED MAGNUS EFFECT PROPELLER

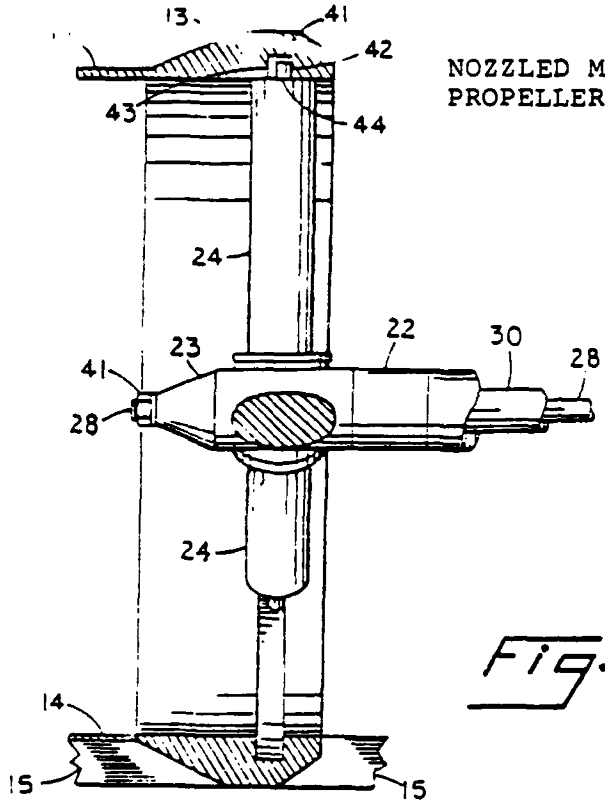

Fig. 3

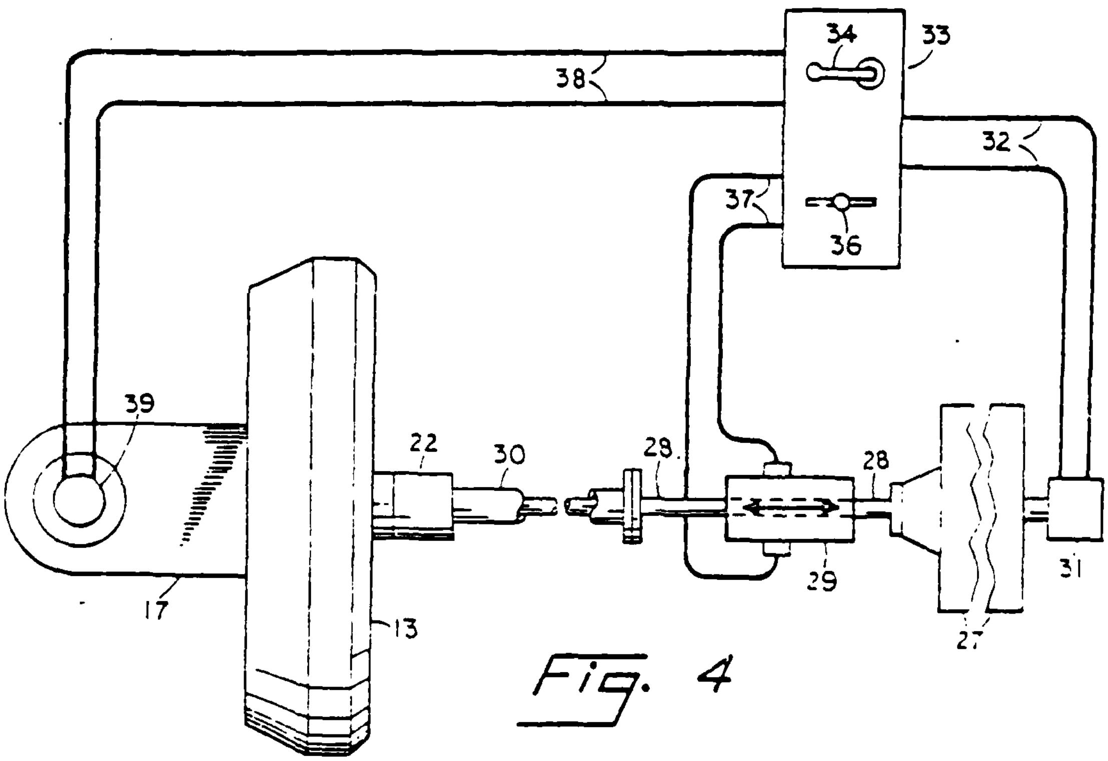

Fig. 4

SHIP STEERING

W. ROOS, RUDDER FOR SHIPS, U.S. PATENT 1,697,779, ISSUED JANUARY 1, 1929 AND BRITISH PATENT 249,730, ISSUED APRIL 1, 1926

The Roos steering system establishes the fact that Magnus effect rudders are within the area of Public Domain in the United States and Great Britain and thus can now be used by anyone without royalty agreements.

The rollers are sausage-shaped and lack the necessary end plates for high coefficients of lift.

- Figure 1 shows how the rudders pass through the air-water interface. This would cause ventilation and result in a loss of lift and turning force.

- Figure 4 shows how a single rotor can maneuver in a fashion similar to a conventional rudder.

- In Figure 5, a bow rotor has been added and the vessel is now capable of pivoting about its midpoint.

- Figure 6 illustrates how the bow and stern rudders can cause the ship to move sideways or "flank".

- The plan view of the stern in Figure 7 depicts a single screw, twin rudder arrangement which the inventor claims will not only steer but will enhance the hydrodynamic efficiency of the propeller.

- Figures 8-14 show drive and control systems.

ASSESSMENT: The Roos invention is conceptually valid. The ability to maneuver in the manner which he describes would be desirable in a replenishment-at-sea operation.

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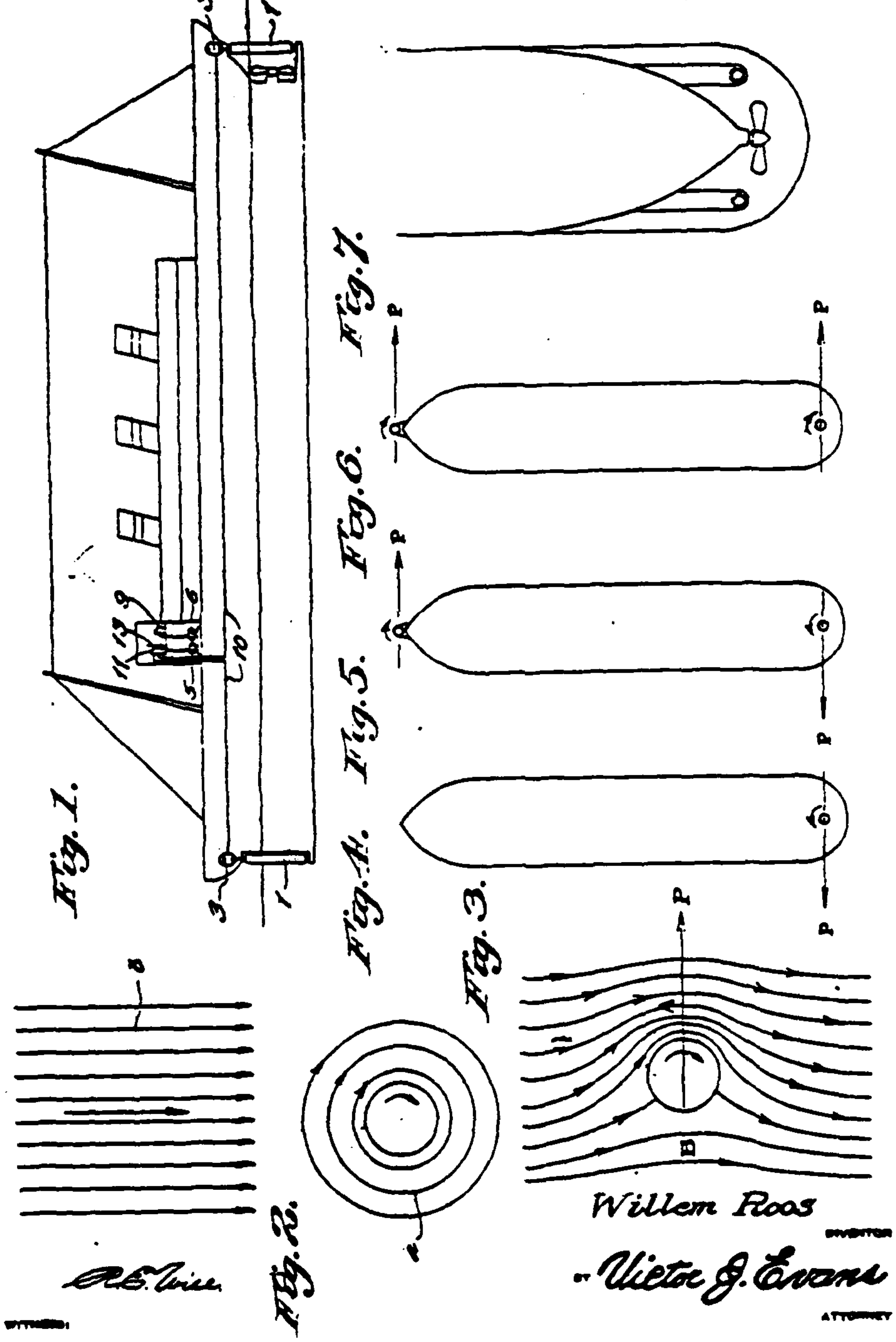
Jan. 1, 1929. 1,697,779

W. ROOS

RUDDER FOR SHIPS

Filed June 15, 1925 4 Sheets-Sheet 1



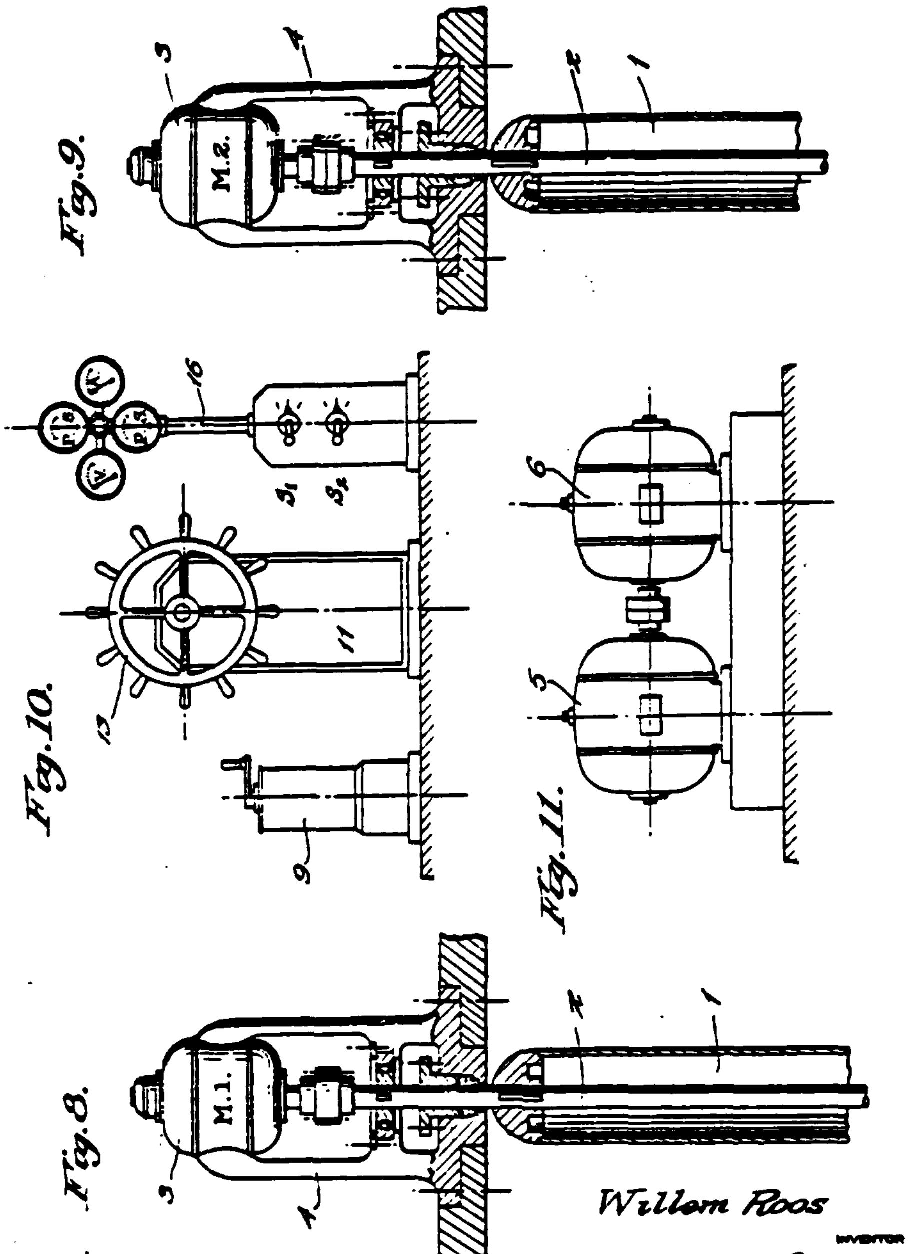
162

Jan. 1, 1929. 1,697,779

W. ROOS

RUDDER FOR SHIPS

Filed June 15, 1925 4 Sheets-Sheet 2



Willem Roos

INVENTOR

R. E. Cole

BY Victor J. Evans

WITNESS:

ATTORNEY

162

Jan. 1, 1929. W. ROOS 1,697,779

RUDDER FOR SHIPS

Filed June 15, 1925 4 Sheets-Sheet 3

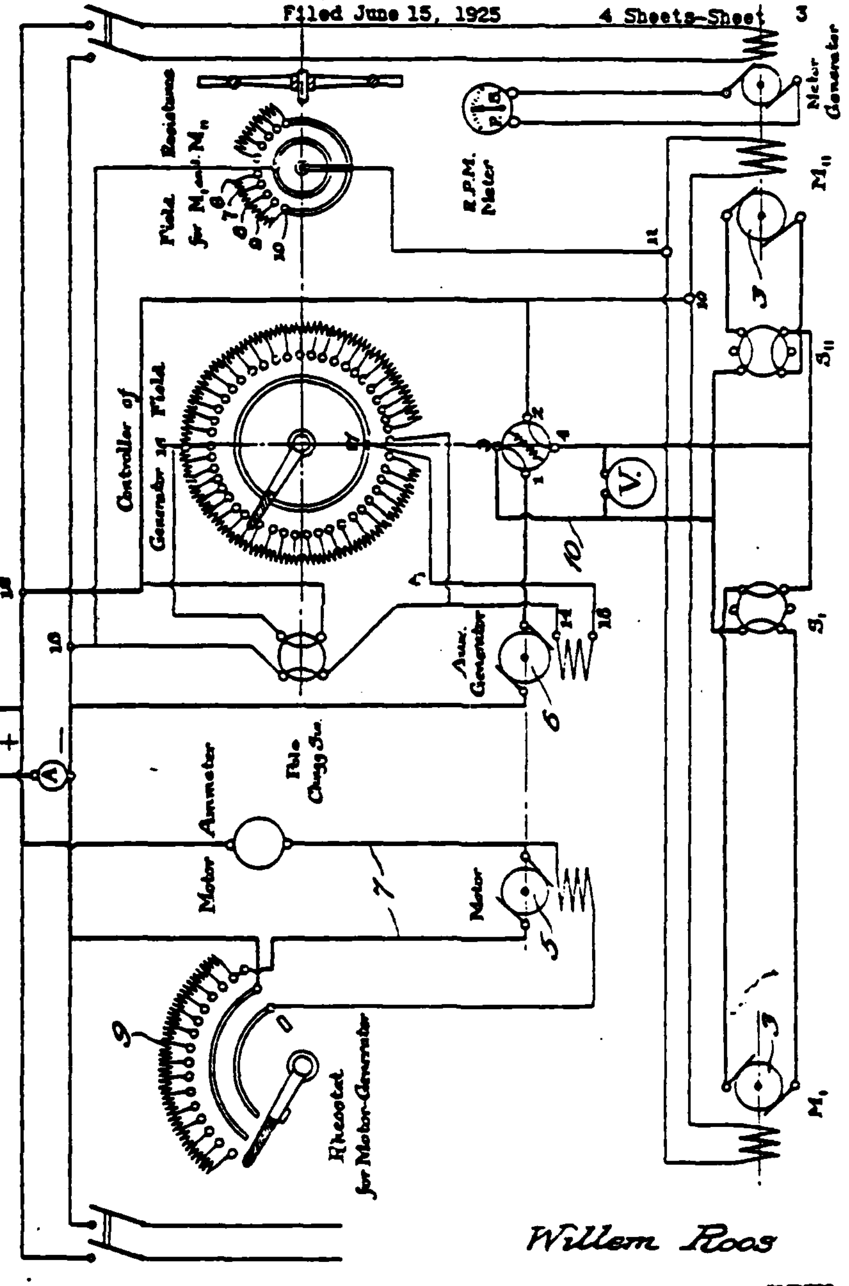


Fig. 12.

Willem Roos

INVENTOR

BY Victor J. Evans

ATTORNEY

R. E. Wise

WITNESS

Jan. 1, 1929. 1,697,779

W. ROOS

RUDDER FOR SHIPS

Filed June 15, 1925 4 Sheets-Sheet 4

Fig. 14.

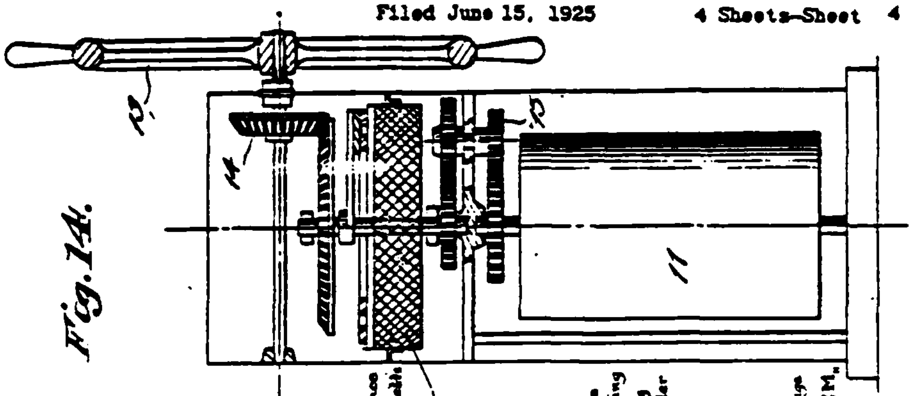
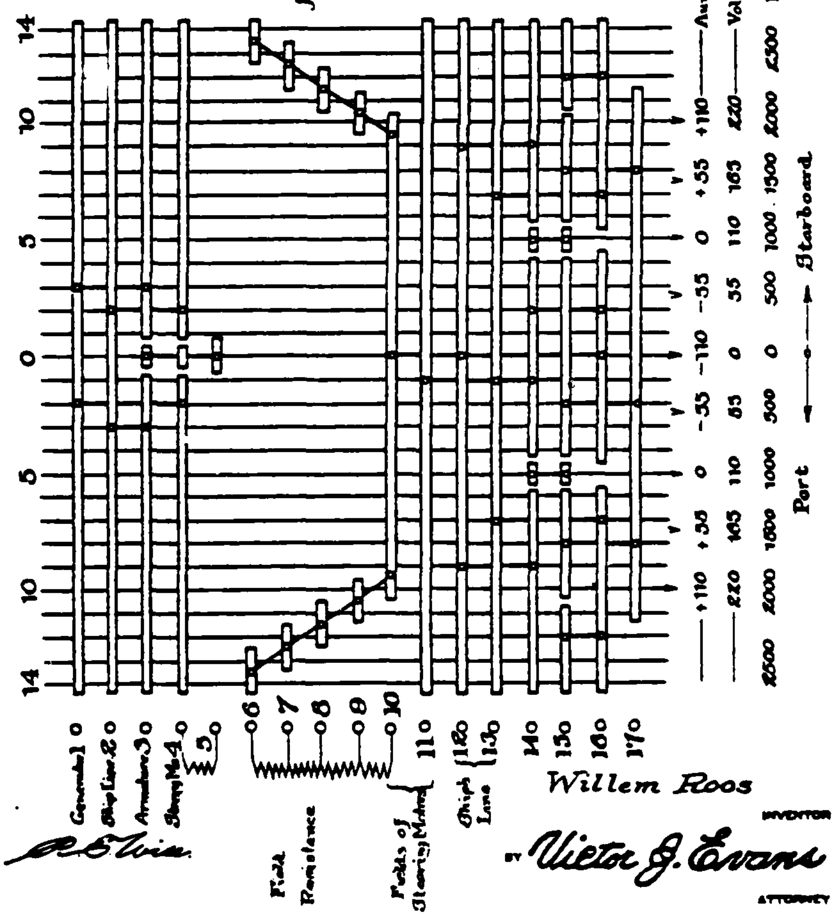


Fig. 13.



WITNESS: R. E. Elvis

Willem Roos

INVENTOR

BY Victor J. Evans

ATTORNEY

G. GASPARINI, IMPROVEMENTS IN OR RELATING TO ROTATABLE RUDDERS, BRITISH PATENT 284,940, ISSUED TO AN ITALIAN SUBJECT, FEBRUARY 9, 1928

Gasparini's rudder claims to be an improvement over the Roos steering system.

- Figure 1 shows the rotor to have rudimentary end disks and that it is intended to replace the conventional rudder on an existing vessel.

- Figure 2 is a flow and force diagram of the rudder in plan view.

ASSESSMENT: Although the end plates would have to be somewhat larger for optimum efficiency, this design is essentially the same as a modern Magnus effect rudder.

[This Drawing is a reproduction of the Original on a reduced scale.]

FIG. 1

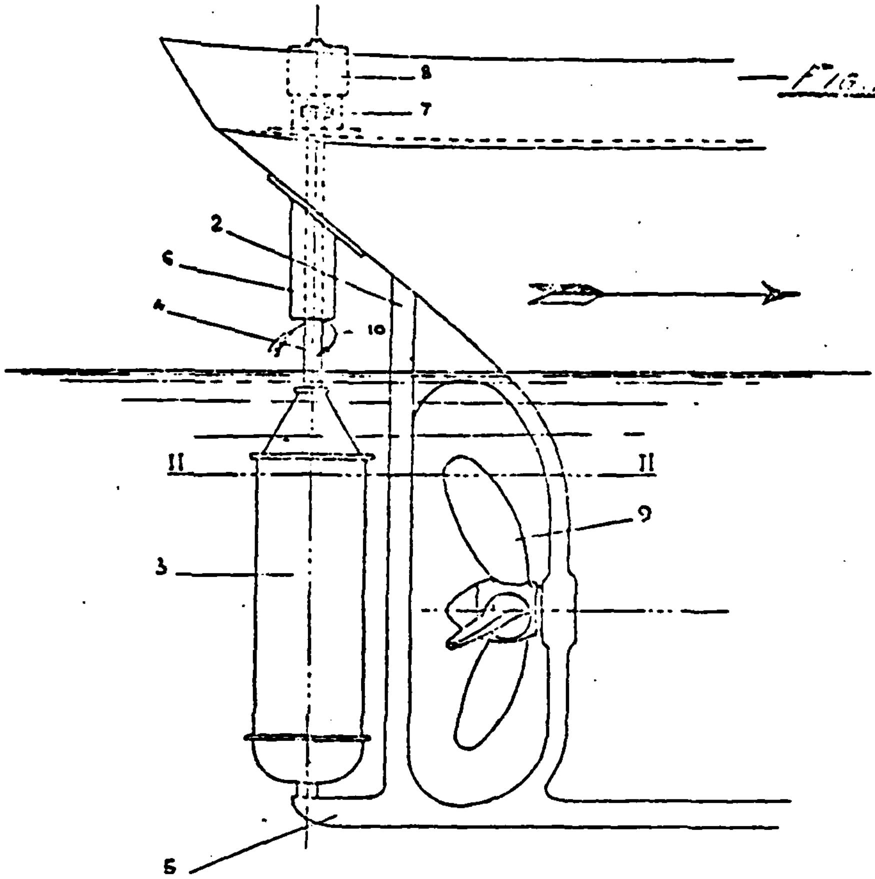
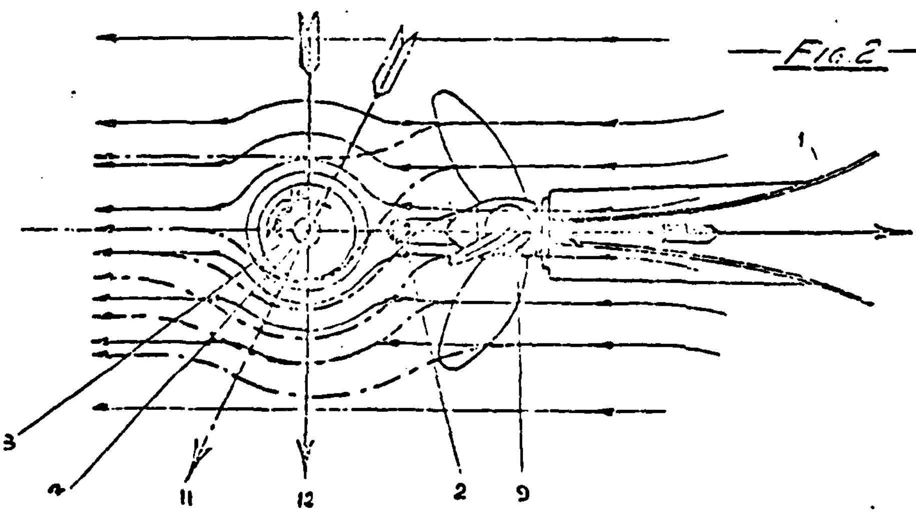


FIG. 2



Charles & Read Ltd Photo Litho

F. WEISS ET AL, METHOD FOR PRODUCING A THRUST IN MANOEUVERING ENGINES FOR A WATERCRAFT AND A MANOEUVERING ENGINE CONSTRUCTED FOR THE SAME, U.S. PATENT 4,316,721, ISSUED FEBRUARY 3, 1982. ASSIGNED TO JASTRAM-WERKE GmbH KG, HAMBURG FEDERAL REPUBLIC OF GERMANY

This invention is not strictly a Magnus effect device, but is a water jet engine that employs rotors for thrust enhancement and steering in one of its embodiments.

- In Figures 9 and 10 the rotor (items 200 and 201) replaces the secondary or diffuser nozzle (item 30), resulting in an assembly that is considerably shorter in overall length. When rotated in opposite directions, the rotors control the jet expansion via the rotor speed. If the rotors rotate in the same direction the arrangement can bring about a deflection of the jet flow as indicated by arrows in Figure 10. This is a large advantage in the case of fixed, non-rotary engines.

ASSESSMENT: The text of the patent is not explicit about how the maneuvering engine is to be installed in a ship. If the assumption is made that the device is to be a "bow thruster," mounted in athwartship tubes, the ability to deflect the jet flow in a forward or aft direction would be highly desirable. The vessel could then be propelled as well as maneuvered by the same system. Considering the recent date of patent issue (1982) it is very likely the thruster is still in the development stage at Jastram-Werke. It is advisable to contact the firm for further information.

United States Patent [19]

Weiss et al.

[11] **4,316,721**

[45] **Feb. 23, 1982**

[54] **METHOD FOR PRODUCING A THRUST IN MANOEUVERING ENGINES FOR A WATERCRAFT AND A MANOEUVERING ENGINE CONSTRUCTED FOR THE SAME**

[75] Inventors: **Friedrich Weiss**, Ahrensburg; **Fred Petersen**, Hamburg, both of Fed. Rep. of Germany

[73] Assignee: **Jastram-Werke GmbH KG**, Hamburg, Fed. Rep. of Germany

[21] Appl. No.: **924,666**

[22] Filed: **Jul. 14, 1978**

[30] **Foreign Application Priority Data**

Jul. 16, 1977 [DE] Fed. Rep. of Germany 2732223
Jun. 29, 1978 [DE] Fed. Rep. of Germany ... 7819548[U]

[51] **Int. Cl.**[3] **B63H 11/02**

[52] **U.S. Cl.** **440/47; 440/38;** 60/221; 417/177; 239/265.19

[58] **Field of Search** .... 239/265.11, 265.19, 239/265.13, 380, 451, 461; 114/151; 244/206; 115/11, 12 R, 12 A, 14, 15, 39, 42; 60/221, 222; 417/177; 440/38–47

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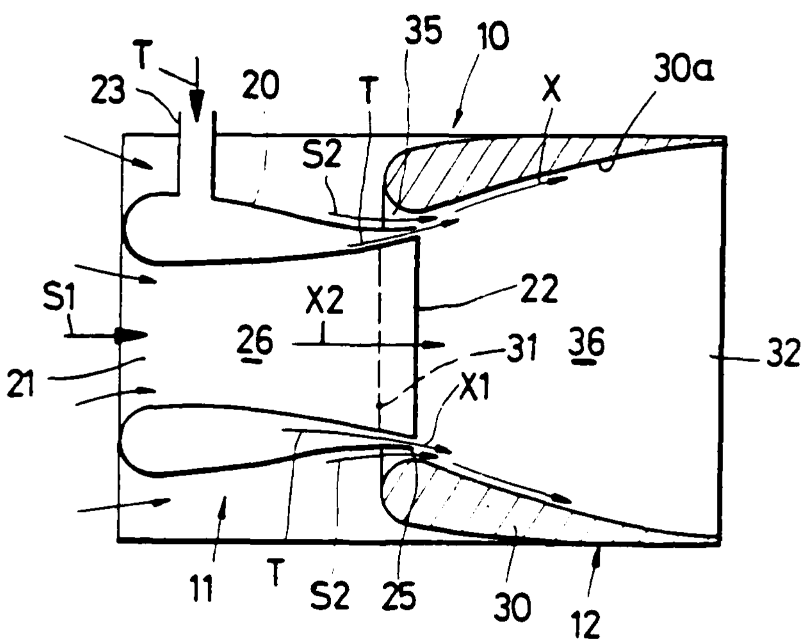
3,606,586	9/1971	Piet	417/177
3,620,183	11/1971	Hull	114/151
3,834,626	9/1974	Sevik	239/265.13

Primary Examiner—Trygve M. Blix
Assistant Examiner—D. W. Keen
Attorney, Agent, or Firm—Toren, McGeady & Stanger

[57] **ABSTRACT**

The invention relates to a method for producing a thrust in manoeuvering engines for watercraft and a manoeuvering engine constructed for the same, whereby the method comprises the annular driving water jet supplied to the diffuser and enveloping a first suction water jet is fed to a second suction water jet supplied to the diffuser inner wall surface, while the manoeuvering engine is constructed in such a way that the rear part of the engine casing is provided with an inlet port having a smaller diameter than the outlet port and located in the vicinity of the outlet port of the front engine part, whereby for the optimum adaptation of the exit mixing jet velocity to the vehicle speed a water jet exit cross-section regulating device is provided.

13 Claims, 12 Drawing Figures



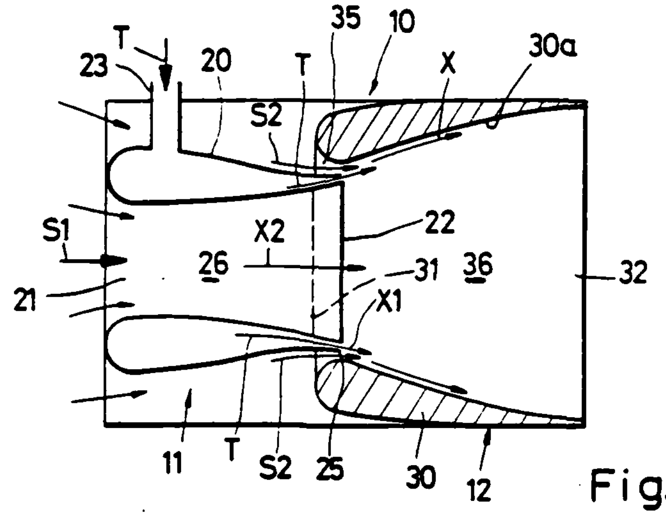


Fig.1

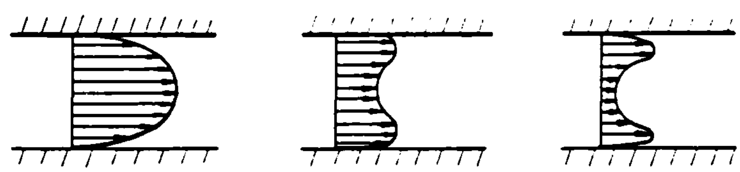


Fig.2a Fig.2b Fig.2c

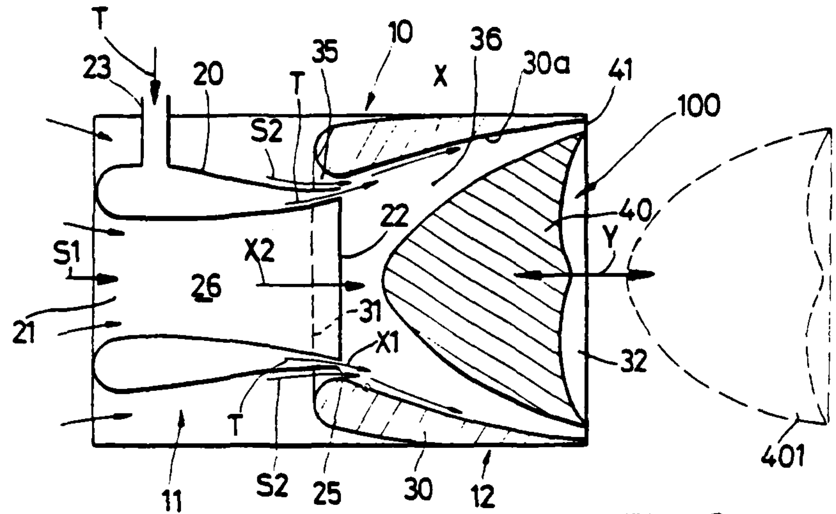

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Fig. 3

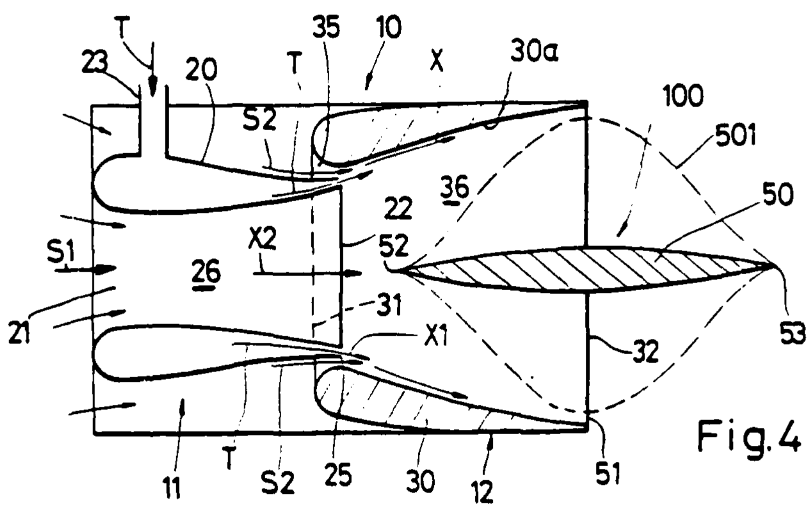
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Fig.4

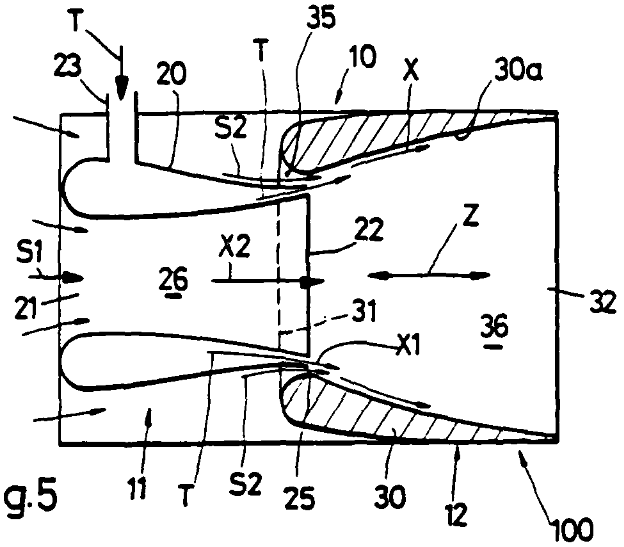
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Fig.5

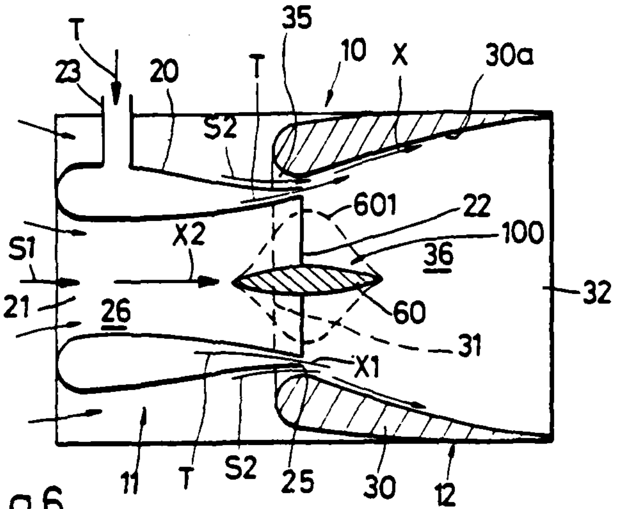
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Fig.6

Fig. 7

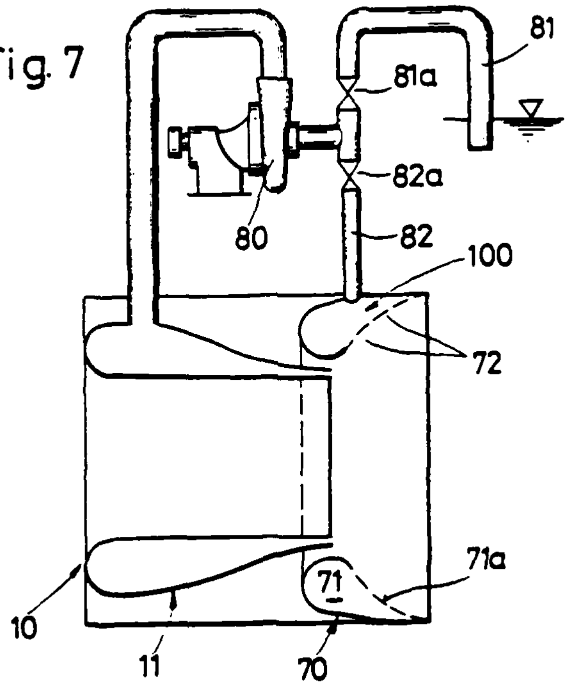
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Fig. 8

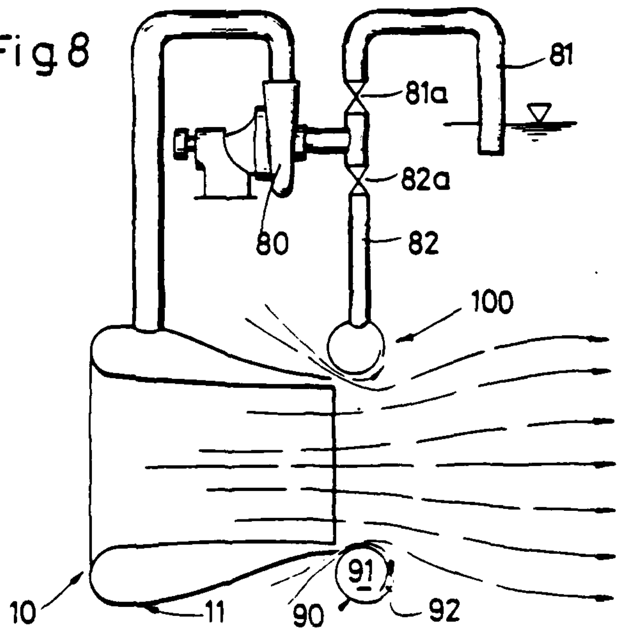
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Fig.9

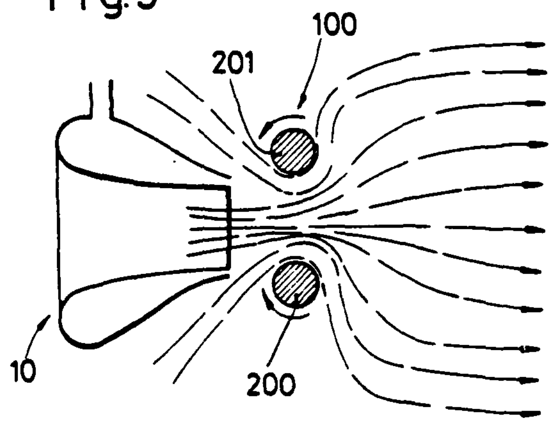
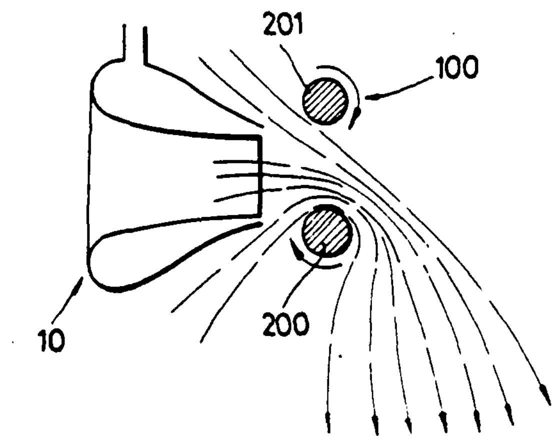


Fig.10



SHIP STABILITY

F.V.A. PANGALILA, FIXED ANGLE STABILIZING FIN SYSTEM, U.S. PATENT 3,757,723, ISSUED SEPTEMBER 11, 1973. ASSIGNED TO JOHN J. McMULLEN ASSOCIATES, INC., NEW YORK, NY

This fixed angle stabilizing fin system consists of a pair of retractable fins located below the waterline in the ship's hull. The fins are constructed with an airfoil shaped section and are installed at an angle of 28-30° with respect to the longitudinal waterplane. When a roll is encountered, the fin on the descending side is extended and the fin on the ascending side is retracted, thus tending to minimize the magnitude of the roll. The fins are shifted inboard or outboard by means of a motor or piston actuated by a sensing device which automatically changes the rudder angle to compensate for the yawing tendency caused by the drag of the extended fin.

The inventor claims that his system is less complicated than the conventional variable pitch anti-roll stabilizers and that being fully retractable, it would be less vulnerable to damage from flotsam.

A second embodiment shows two pairs of fins, one of each pair on a side, having a negative angle of attack. This second set is extended on the ascending side of the hull during a roll. The extra pair of fins is not only intended to increase the effectiveness of the system but also to reduce the yawing motion.

A third embodiment calls for the fins to be constructed from a series of rods or tubes arranged in an airfoil configuration. When the tubes are rotated by motors, the Magnus effect will take place and enhance the roll dampening action of the fin.

- Figure 1 is a simplified front view of a ship equipped with a fixed angle stabilizer system.

- Figure 2 is a perspective view of a fin stabilizer fit in the starboard side of a ship.

- Figure 3, (a) through (i), is a sequential series of drawings showing a rolling ship equipped with a fin stabilizer system.

- Figure 4, (a) and (b), is an illustration of a fixed angle fin provided with a cover plate for streamlining the ship when the fin is in storage.

- Figure 5 shows the Magnus effect version of the fin.

- Figure 6 is the drive system for the retractable rotors.

- Figure 7 is a block diagram illustrating the manner in which a roll sensor controls the operation of the fixed angle stabilizing fin system and the steering rudder.

ASSESSMENT: The motor-driven shiftable rollers would be complicated and expensive to build; whereas a single retractable rotor would serve the same purpose and would not need to be positioned at any specific angle of attack in order to provide lift.

The patent is assigned to a major U.S. naval architecture firm that would have to be negotiated with concerning rights and possible royalties in future rotary stabilizer applications.

United States Patent [19]

Pangalila

[11] **3,757,723**

[45] **Sept. 11, 1973**

[54] **FIXED-ANGLE STABILIZING FIN SYSTEM**

[75] Inventor: Frans V. A. Pangalila, Waddinxveen, Netherlands

[73] Assignee: John J. McMullen Associates, Inc., New York, N.Y.

[22] Filed: Apr. 7, 1971

[21] Appl. No.: 132,160

[52] U.S. Cl. 114/126
[51] Int. Cl. B63b 43/04
[58] Field of Search 114/126; 244/123

[56] References Cited

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1,301,936 7/1962 France 114/126

Primary Examiner—Milton Buchler
Assistant Examiner—Stuart M. Goldstein
Attorney—Fleit, Gipple & Jacobson

[57] **ABSTRACT**

A ship stabilization system comprising at least one pair of fixed-angle fins retractable into the hull of the ship. The moment developed by each fin is proportional to the area of the fin exposed to the external waters. In one embodiment, the fin is composed of a plurality of spinning rods or tubes. Also disclosed is a system for linking the fins with the ship's rudder thereby compensating for expected course changes of the ship.

19 Claims, 7 Drawing Figures

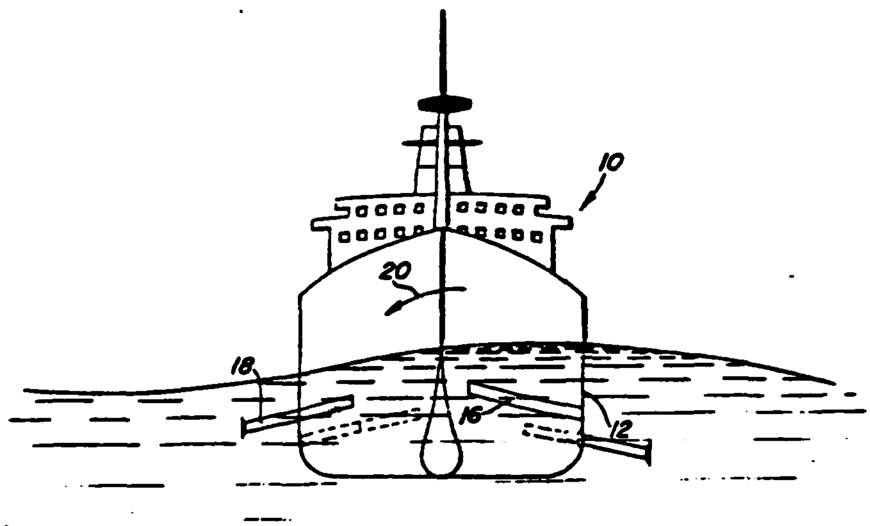


Fig. 1

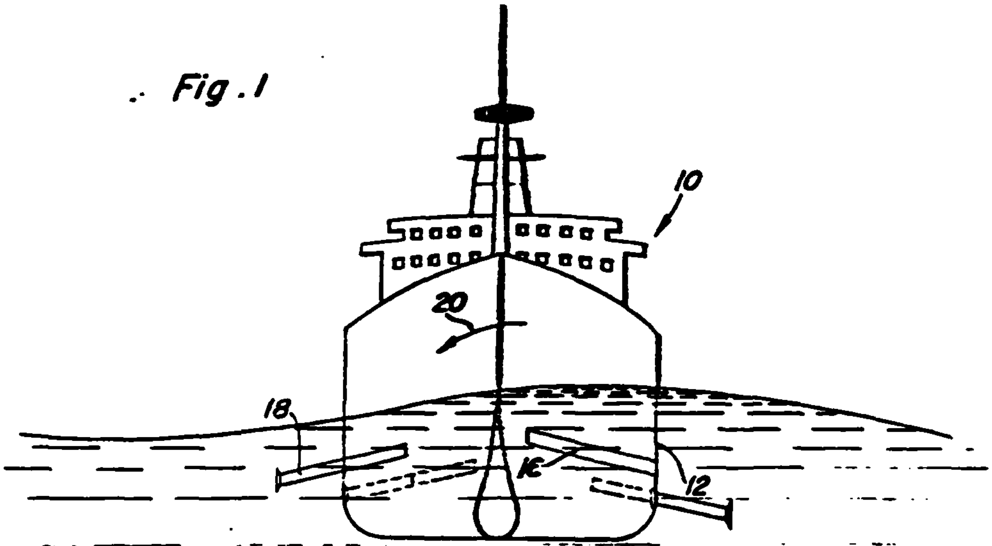


Fig. 2

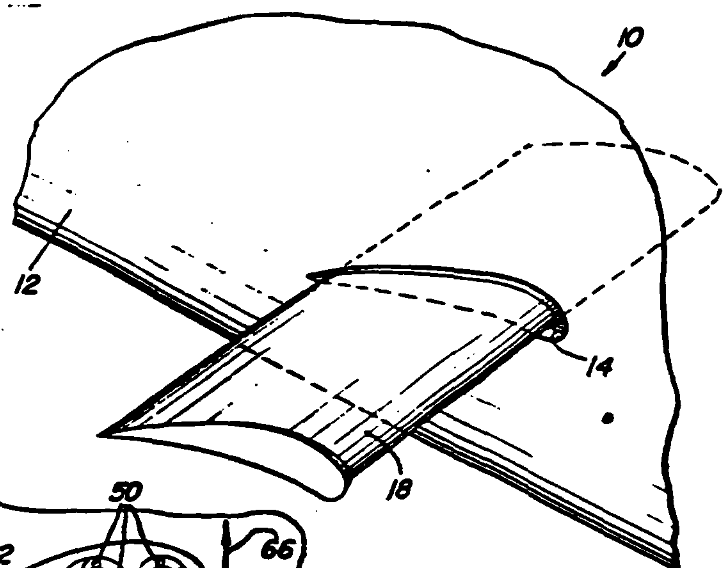
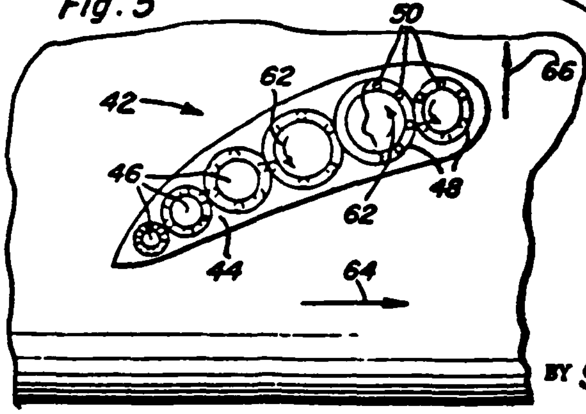


Fig. 5



Frans V.A. Pangalila
INVENTOR

BY Fleit, Gipple & Jacobson
ATTORNEYS

Fig. 3

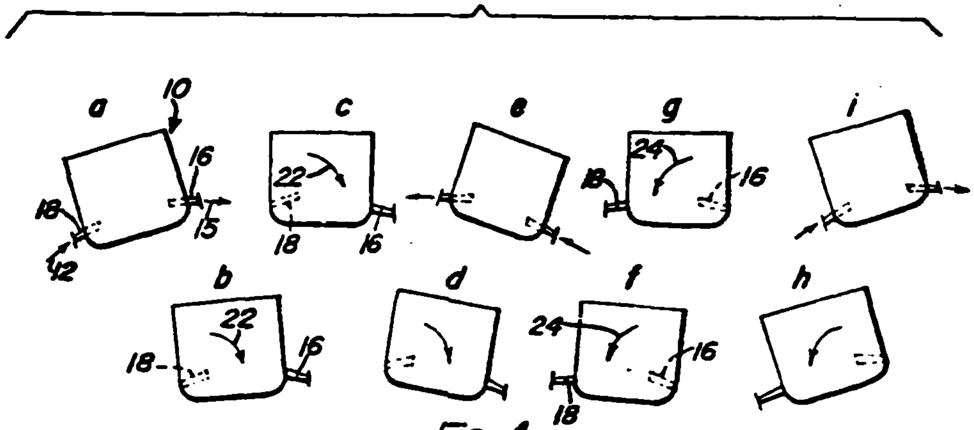


Fig. 4

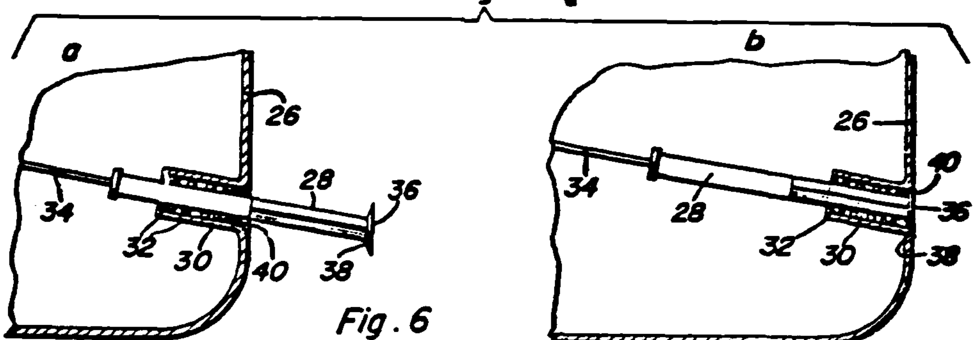


Fig. 6

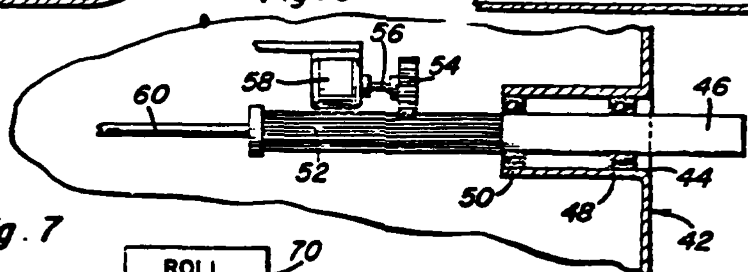
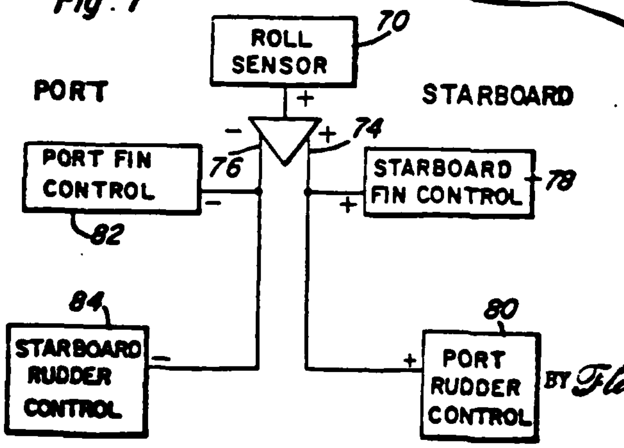


Fig. 7



Frans V. A. Pangalila
INVENTOR

BY Fleit, Gipple & Jacobson
ATTORNEYS

W.M. KOLLENBERGER, DECEASED, STABILIZING DEVICE FOR SHIPS, U.S. PATENT 4,161,154, ISSUED JULY 17, 1979. ASSIGNED TO HOWALDTSWERKE-DUETSCHE MEFT AKTIENGESLLSCHAFT HAMBURG UND KIEL, KIEL, FEDERAL REPUBLIC OF GERMANY

This stabilizing device employs a plurality of retractable rotors.

- Figure 1 is a schematic flow diagram of liquid with a rotor turning in a clockwise direction.

- Figure 2 is a diagram showing a part of a ship in which one rotor is provided on the port side and one on the starboard side.

- Figure 3 shows an embodiment similar to that of Figure 2 but in which two rotors are disposed on each side of the ship.

- Figure 4 illustrates a modification to Figure 3 in which rotors are disposed one within the other on one side.

- Figure 5 is a diagram showing a rotor with a guide disposed downstream of the rotor.

- Figure 6 is an elevation view of a rotor having end covering parts.

- Figure 7 is a view of the inner rotor with the upper half in cross-sectional, the lower half in plan view.

- Figure 8 shows a perspective view of the outer rotor with the corresponding drive, seen in cross-section.

- Figure 9 is showing the outer rotor with the corresponding drive and the displacement device.

- Figure 10 is a partial elevation serving to explain how the drive motor is provided with energy.

The inventor states that a ship with a speed of 10 meters per second (about 19.5 knots) would require a rotor with a peripheral velocity of 35 meters per second.

Assuming a rotational speed of the rotor of 1450 rpm, its diameter would be 0.462 meters. If, for example, a fin having an area of 4 square meters (a length of 2.67 meters and a depth of 1.5 meters) and having a coefficient of lift approximately equal to 1.0 is replaced by a rotor attaining a coefficient of lift equal to approximately 7.0, its area would have to be 0.57 meters and its length then would be 1.23 meters. The rotor is substantially more advantageous in respect to space than is the fin by a factor of 7.

ASSESSMENT: Kollenberger's concept not only provides for Magnus effect stabilizers but also eliminates the problem of rapid drive reversal by using dual rotors and sliding them in and out as needed to counter the ship's roll. The stabilizer configuration called for in this patent is very close to what the Navy might require. It is simple, practical, and sturdy. The assignee in Germany should be contacted for further information.

United States Patent [19]

Kollenberger, deceased

[11] **4,161,154**

[45] **Jul. 17, 1979**

[54] **STABILIZING DEVICE FOR SHIPS**

[75] Inventor: **Walter M. Kollenberger, deceased,** late of Hamburg, Fed. Rep. of Germany, by Kathe L. M. Kollenberger, administratrix

[73] Assignee: **Howaldtswerke-Deutsche Werft Aktiengesellschaft Hamburg und Kiel,** Kiel, Fed. Rep. of Germany

[21] Appl. No.: **873,716**

[22] Filed: **Jan. 30, 1978**

Related U.S. Application Data

[63] Continuation of Ser. No. 784,705, Apr. 5, 1977, abandoned, which is a continuation-in-part of Ser. No. 697,755, Jun. 21, 1976, abandoned, which is a continuation of Ser. No. 595,334, Jul. 14, 1975, abandoned.

[30] **Foreign Application Priority Data**

Jul. 17, 1974 [DE] Fed. Rep. of Germany 2434257

[51] **Int. Cl.**² **B63B 39/00;** B63B 43/02

[52] **U.S. Cl.** **114/122;** 114/121; 114/124

[58] **Field of Search** .... 114/121-126; 214/10, 19, 90 R

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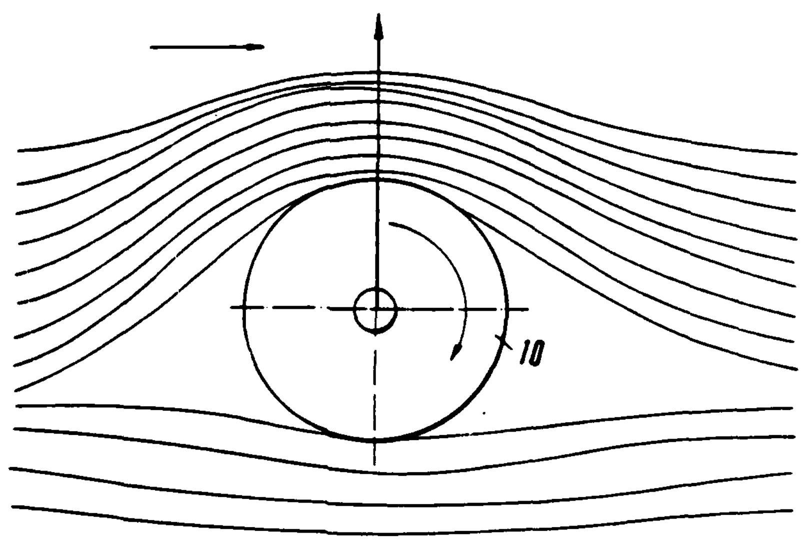
2,985,406	5/1961	Bump	244/10
3,757,723	9/1973	Pangalia	114/126

Primary Examiner—Trygve M. Blix
Assistant Examiner—D. W. Keen
Attorney, Agent, or Firm—Stevens, Davis, Miller & Mosher

[57] **ABSTRACT**

A stabilizing device for a ship comprising two rotors housed one within the other for rotation in opposite directions and positioned on each side of the ship. The rotors are axially movable relative one to the other to permit the outer rotors to be alternately put into and out of action. Guide elements disposed downstream of the rotors and covering parts may be provided to reduce resistance to water flow.

3 Claims, 10 Drawing Figures



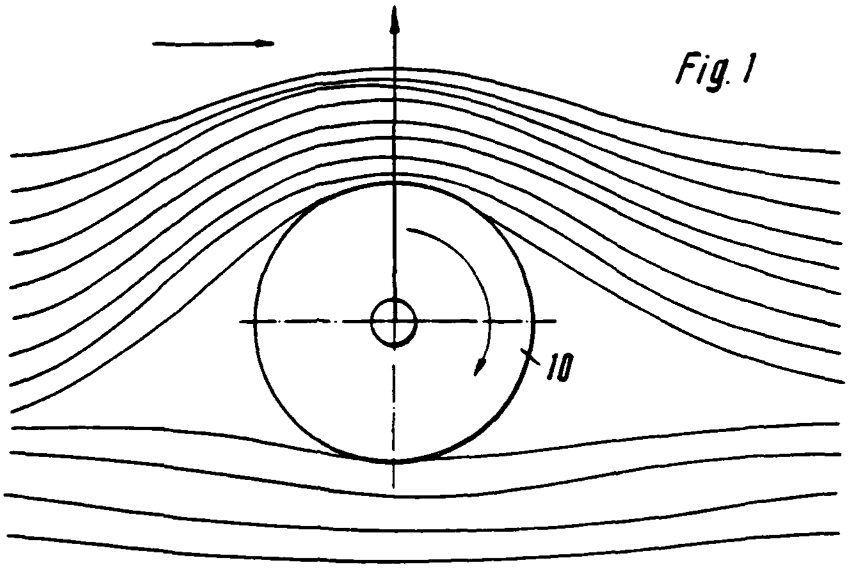


Fig. 1

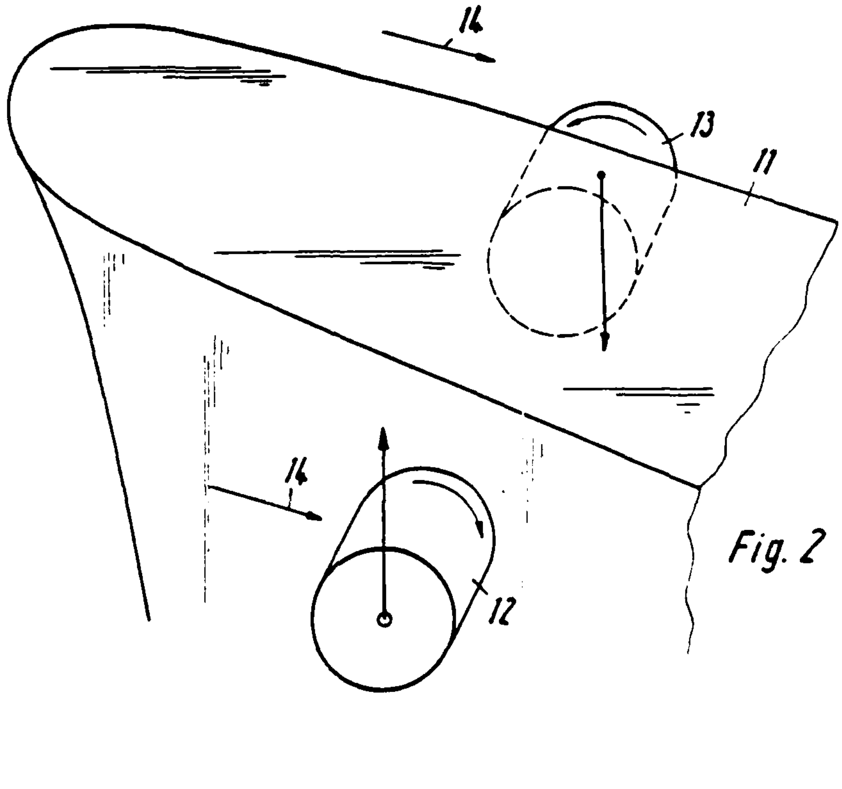


Fig. 2

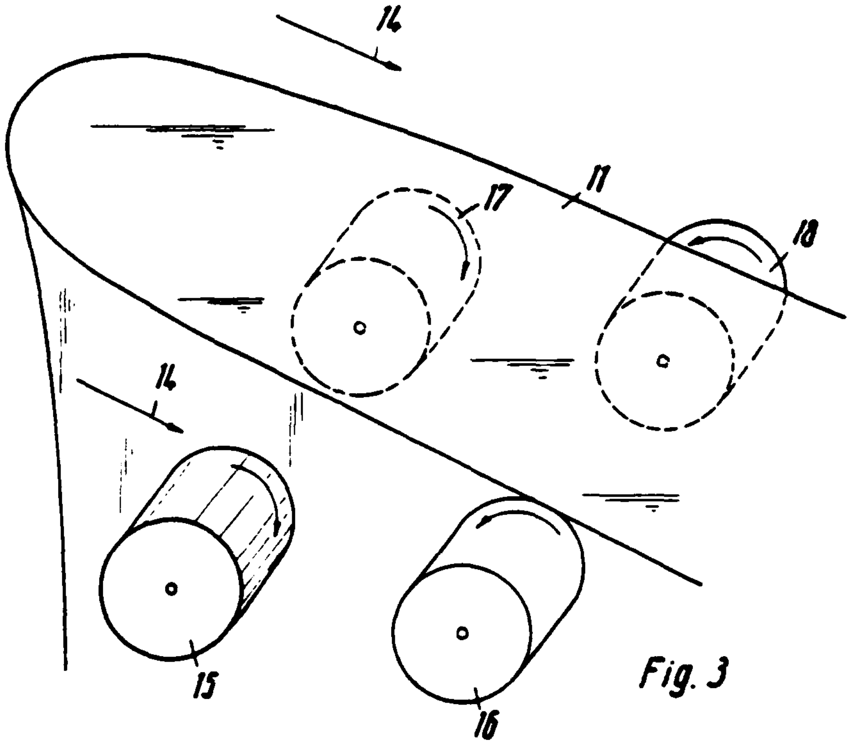


Fig. 3

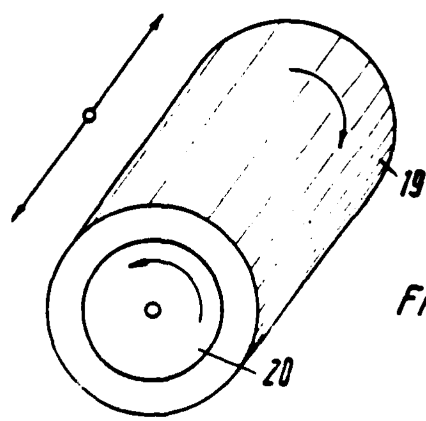
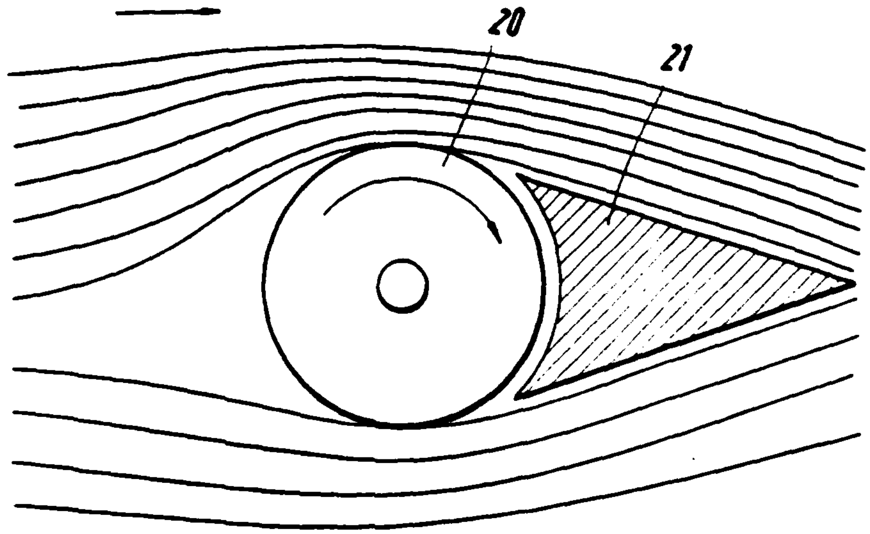


Fig. 4

Fig. 5



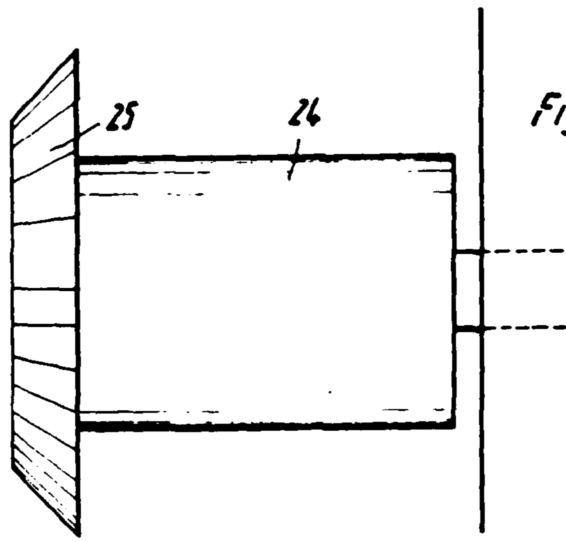
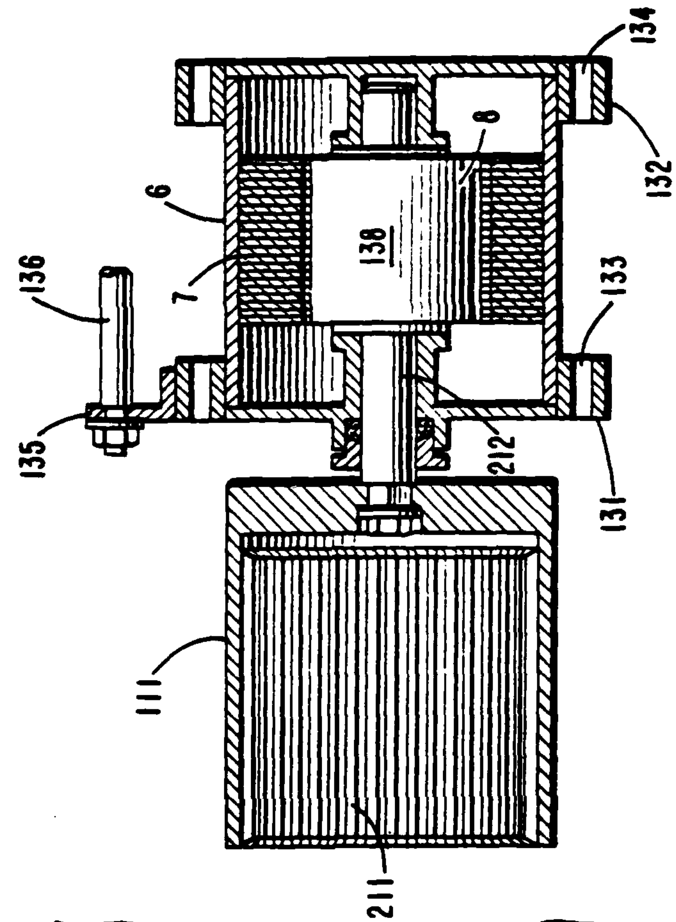


Fig. 6


134
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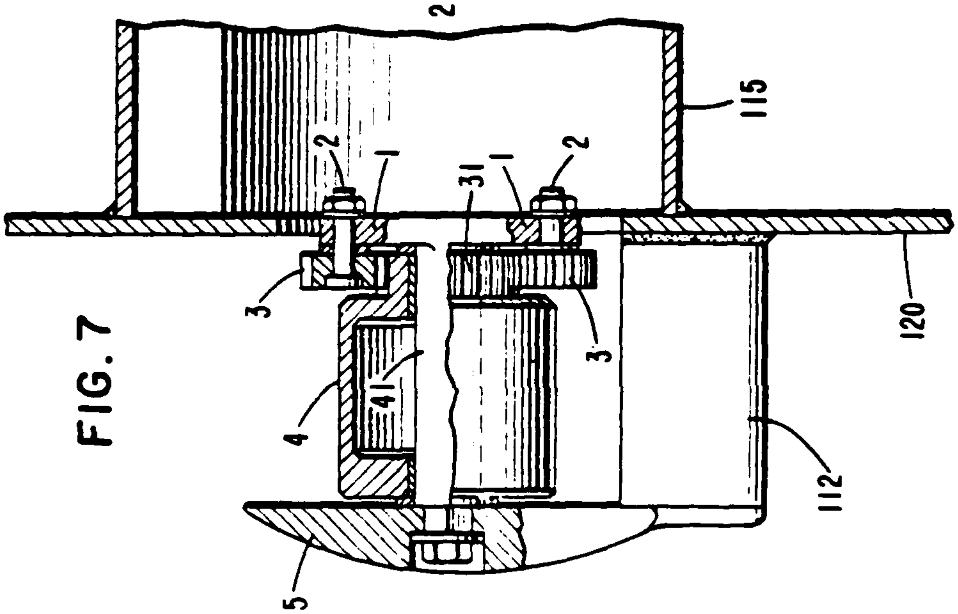
131
111
211

FIG. 8


115
2
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2
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3
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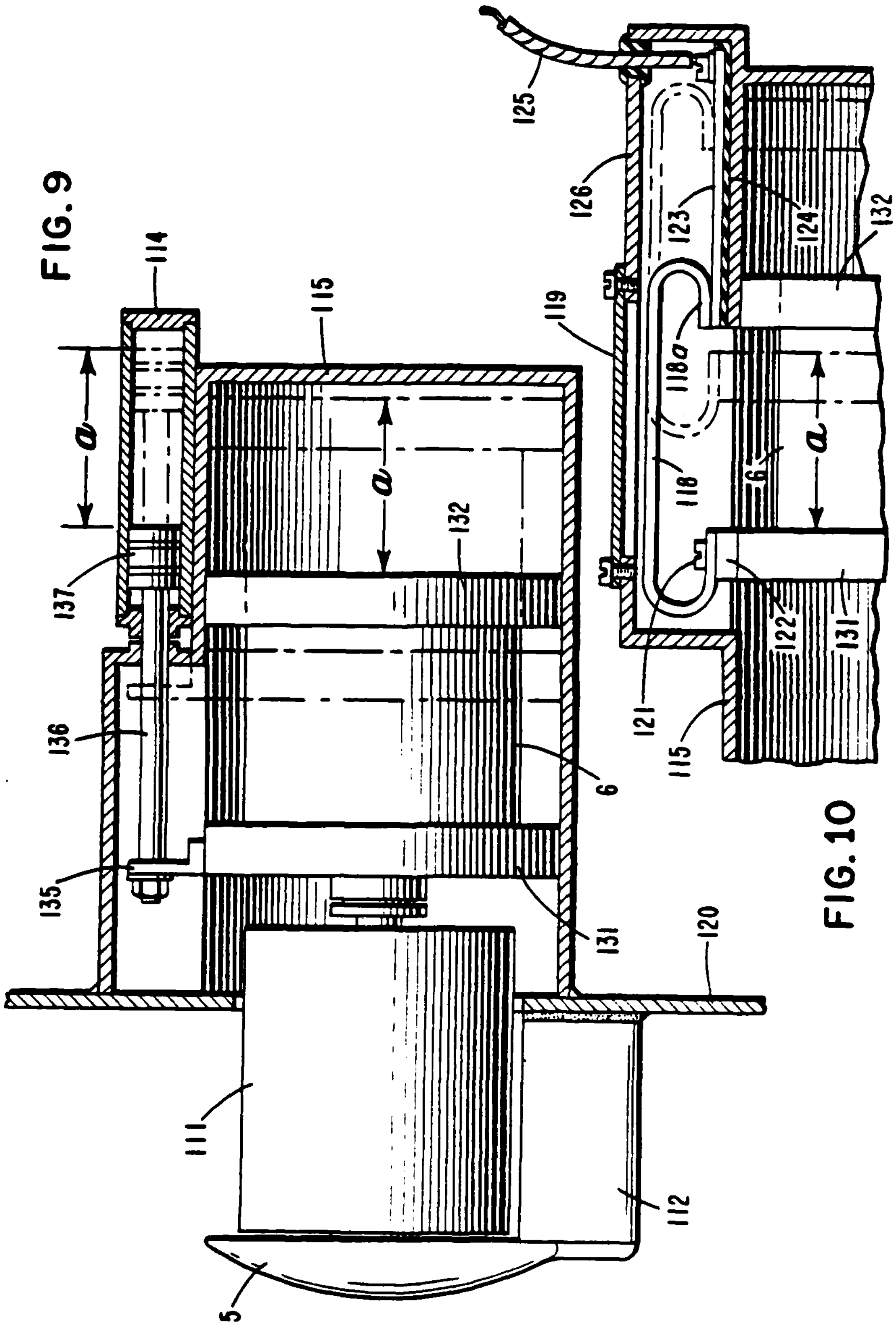
5

FIG. 7

FIG. 9

FIG. 10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136
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135
131
120
111
112
5

ENERGY CONVERTERS

C.E. SARGENT, WIND MOTOR, U.S. PATENT 1,744,924, ISSUED JANUARY 28, 1930

Sargent's patent pertains to vertical axis windmills. Three versions are shown and all employ a vane for wind orientation. Two of the embodiments use a conventional wind wheel to furnish power to spin the rotors. The third embodiment is fitted with wind turbine buckets for that purpose.

The advantages of a cycloidal windmill are that it does not continually hunt for the wind direction and that substantial torque can be developed by mounting the rotors on long crossarms. The disadvantages are that the revolutions tend to be slow and that the rotors produce a driving force only while passing through the two quadrants that are perpendicular to the wind causing some aerodynamic drag while in the idle or side quadrants.

His first wind motor embodiment is shown in Figure 1 (elevation) and Figure 2 (plan). A wind wheel at the top of the assembly turns the main shaft (item 14) and gear assembly (items 31, 32 and 33) causing the rotor frame to revolve around the central axis. A slotted friction guide (item 27) is oriented by means of the vane (item 13). Friction rollers on the windward side impinge on the inner face of the slot causing counterclockwise rotation of the rotors while the opposite occurs on the leeward side. Torque generated by the rotors augments that developed by the windwheel.

- In the second embodiment, illustrated in Figure 4, rotation is reversed by a vane oriented mutiliated gear (items 55 and 56) shown in detail in Figure 5. The rotors are driven by bevel gears.

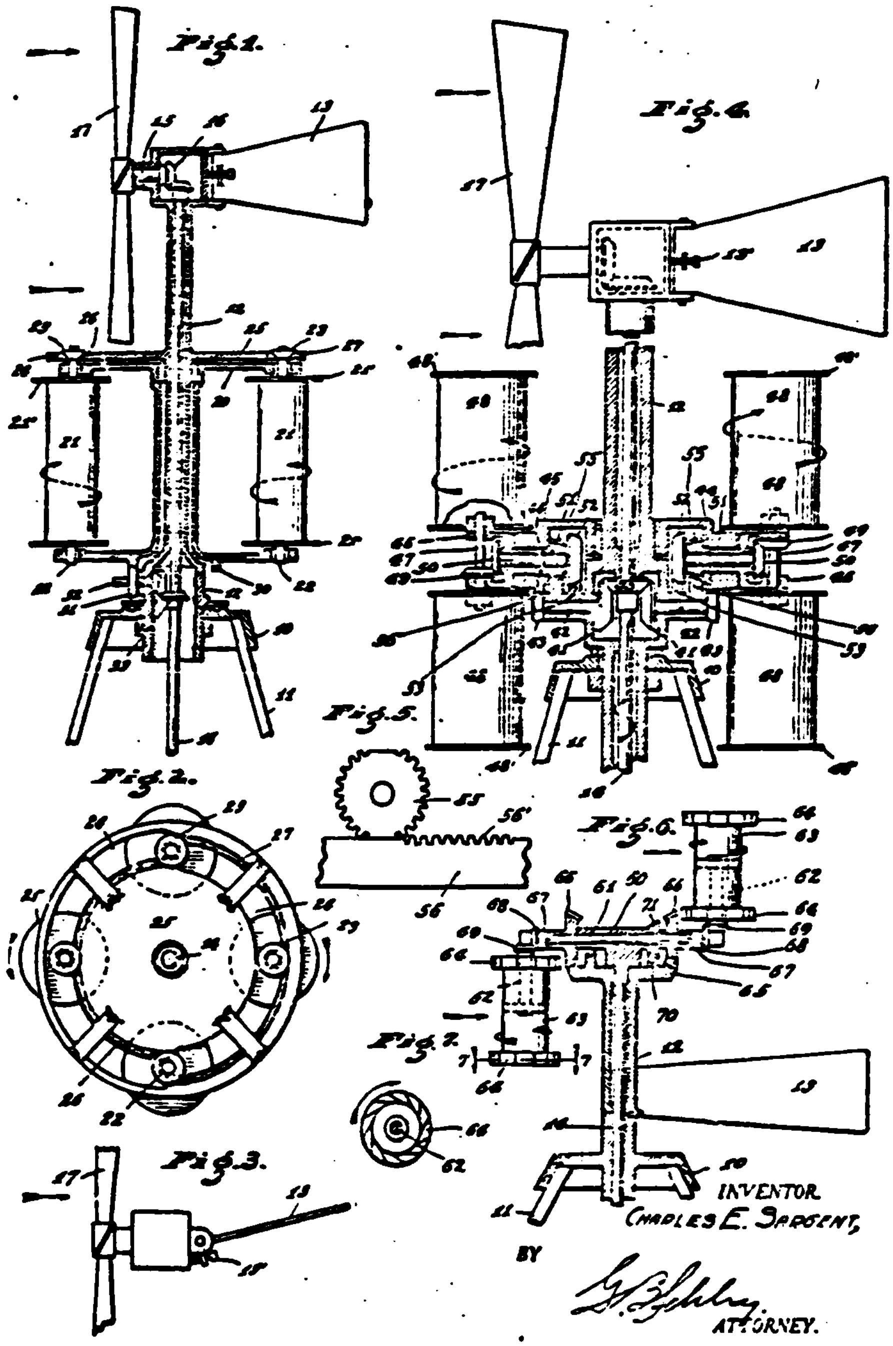
- The third version (Figure 6) has two wind driven rotors and no wind wheel. The rotor frame travels on a multilated bevel gear, again oriented by the vane. The cylinders (item 63) flip over every 180 degrees of revolution so that the windward rotor hangs downward and the leeward rotor swings upward away from the air turbulence caused by the main assembly.

ASSESSMENT: A device similar to Sargents's third type of wind motor might be useful as a power source for a rotor sail.

Jan. 28, 1930. C. E. SARGENT 1,744,924

WIND MOTOR

Filed April 13, 1925



J.D. MADARASZ, WIND ENGINE, U.S. PATENT 1,791,731 ISSUED FEBRUARY 10, 1931

The Madarasz Wind Engine consists of a series of trolley cars on a circular track fitted with Flettner rotor-sails. These units have a wind actuated reversing mechanism and a telescoping feature for altering the height of the cylinders. Each rotor frame contains an electric generator and the generators are connected by a common line.

- Figure 1 is a plan view of the apparatus.
- Figure 2 is an enlarged sectional elevation of one of the rotors.
- Figure 3 is a sectional plan view of a rotor.
- Figure 4 is a plan view of the mechanism for reversing the motor.
- Figure 5 is a transverse section on the line 5-5 of Figure 4.
- Figure 6 illustrates the mechanism for rotating the rotors.
- Figure 7, 8 and 9 show an embodiment of the invention having the rotors mounted on a turntable rather than cars on a track.

Madarasz constructed and demonstrated one of the rotor units of his system but failed to obtain sufficient financial support to complete the entire assembly.

ASSESSMENT: The concept of this gigantic wind engine is valid. In recent times several such generators have been successfully used although they were driven by conventional sails rather than rotors. The potential power available from a system similar to this invention is impressive. Its utility, however, would most probably by in the non-military sector.

Feb. 10, 1931. J. D. MADARASZ 1,791,731

WIND ENGINE

Filed July 23, 1928 3 Sheets-Sheet 1

Fig. 2.

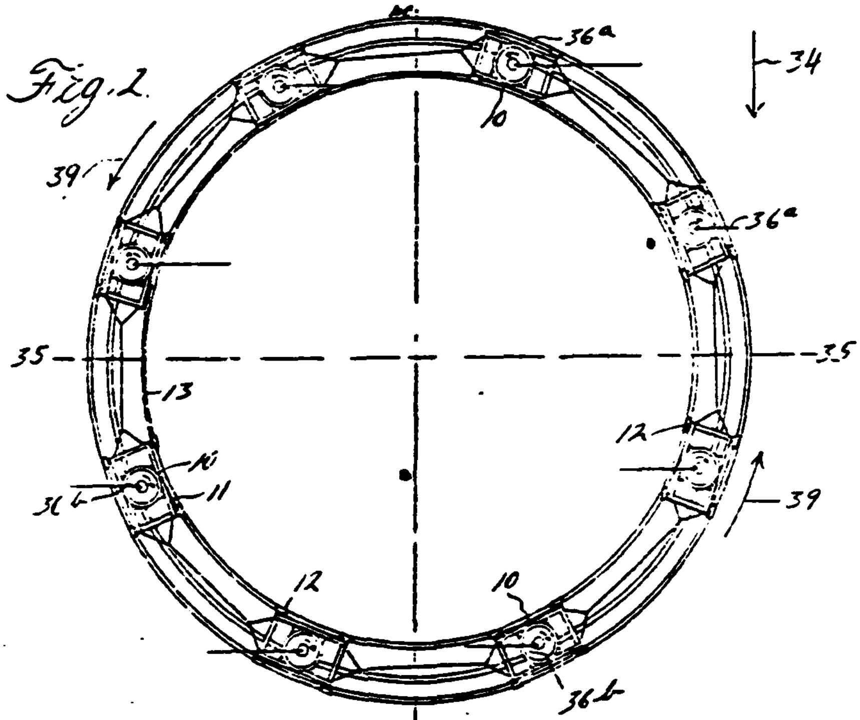
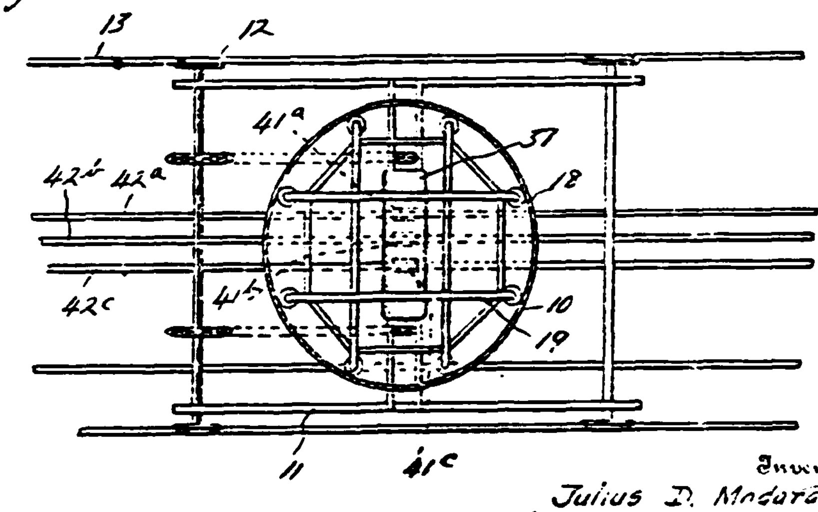


Fig. 3.



Inventor

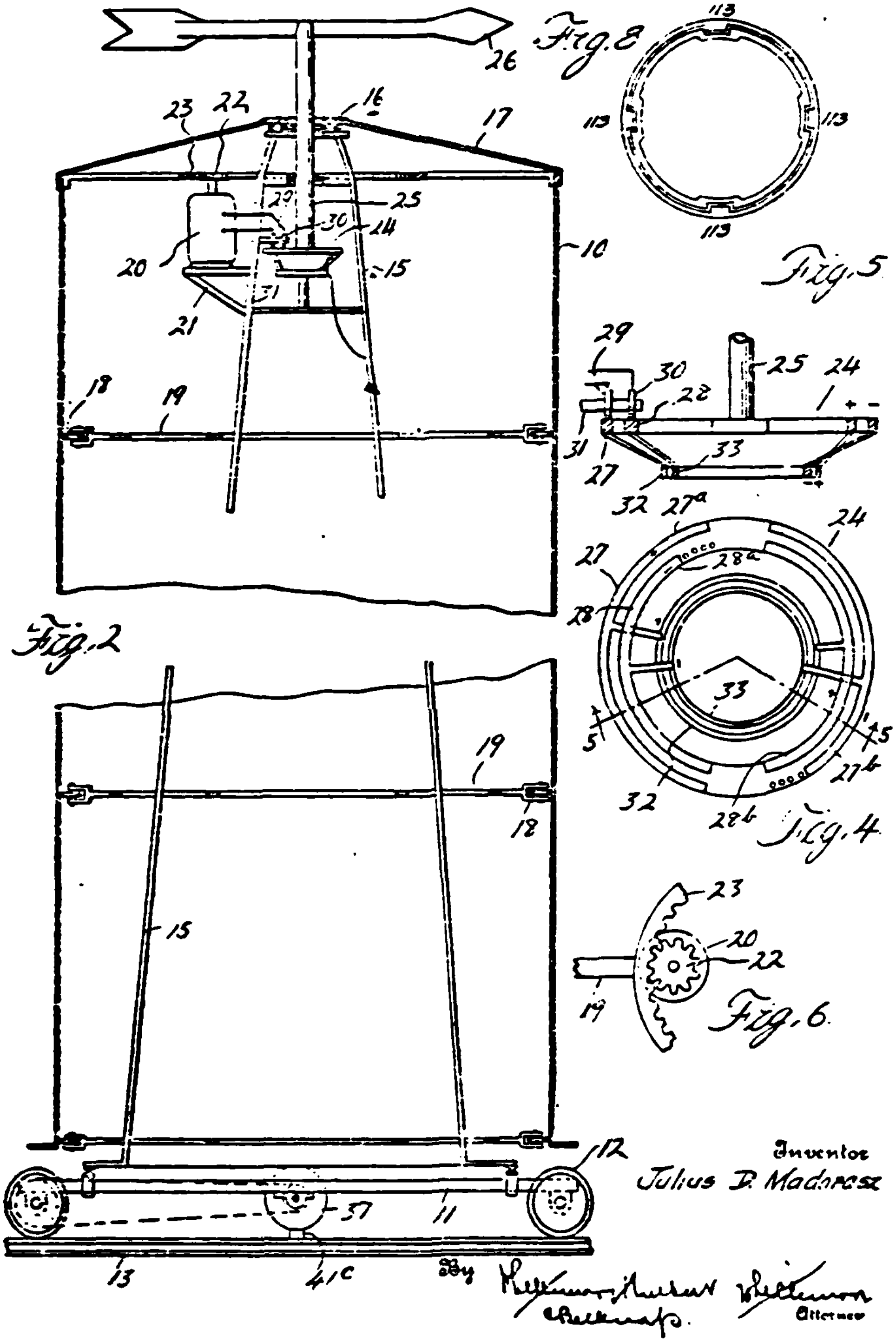
Julius D. Madarasz.

By Whittemore Hulbert Whittemore & Belknap

Attorney

WIND ENGINE

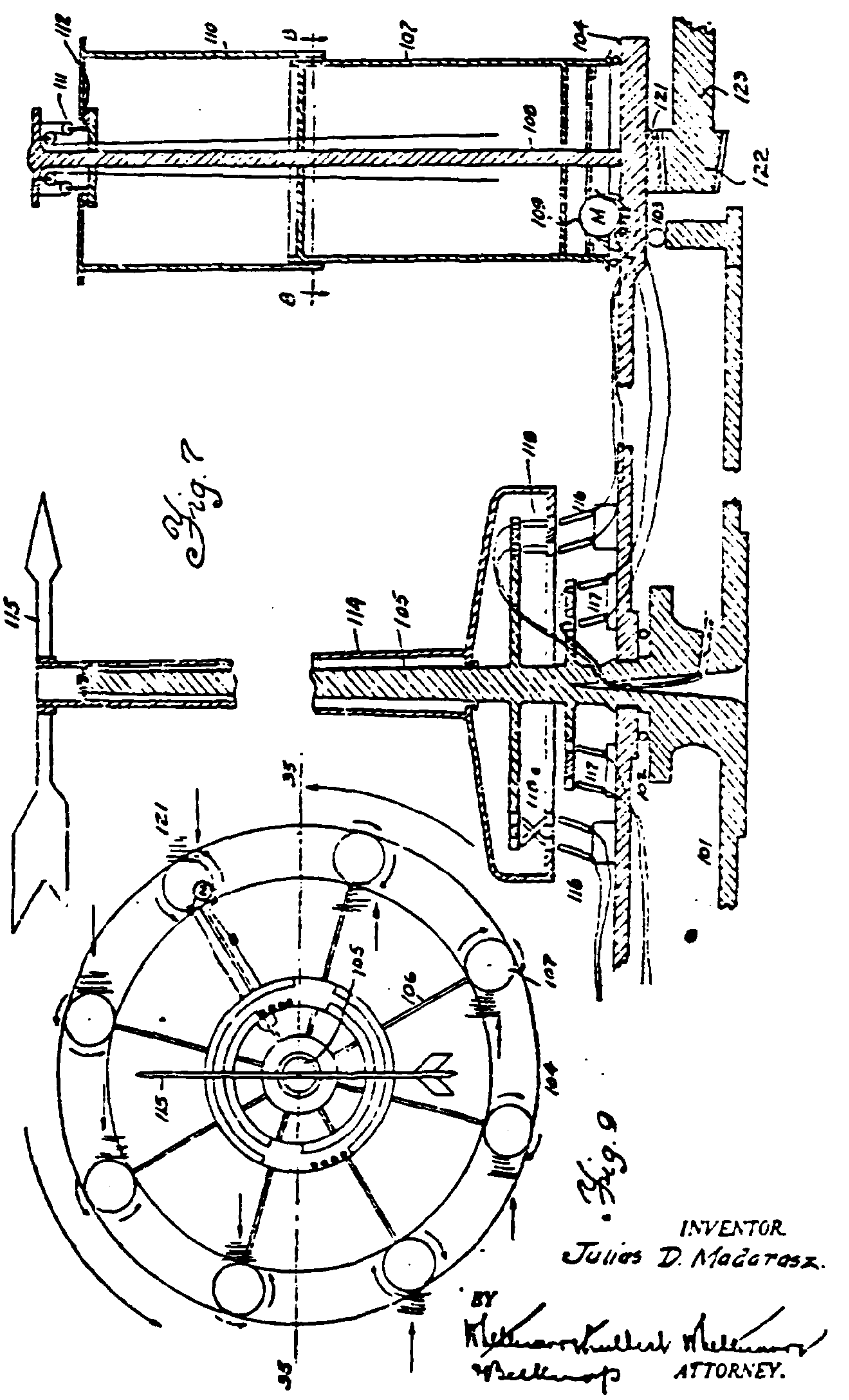
Filed July 23, 1928 3 Sheets-Sheet 2



Feb. 10, 1931. J. D. MADARASZ 1,791,731

WIND ENGINE

Filed July 23, 1928 3 Sheets-Sheet 3



INVENTOR
Julius D. Madarasz.

BY

ATTORNEY.

W.A. CARTER, MECHANISM FOR UTILIZING THE ENERGY OF A CURRENT IN A FLUID, U.S. PATENT 2,078,837, ISSUED APRIL 27, 1937

Carter's invention uses the variation in pressure surrounding a Magnus effect cylinder confined in a tunnel to operate indicators, relays and servomechanisms. The inventor does not propose to extract great amounts of energy from the device.

- Figure 1 is a diagrammatic representation of the invention in which the rotating cylinder is located in a conduit. Means is provided for regulating the flow of fluid through the conduit in accordance with variations in the Magnus effect pressure developed in order that the resultant flow may be maintained uniformly.

- Figure 2 is a section along line 2-2 of Figure 1.

- Figure 3 is a diagrammatic view of a portion of the firebox of a boiler, showing a plurality of air supply tubes and means for regulating the flow of air through these tubes and to the fuel superposed upon the grate.

- Figure 4 is a diagrammatic section through an embodiment of the invention intended for use in the open air.

- Figure 5 is a top plan view of Figure 4.

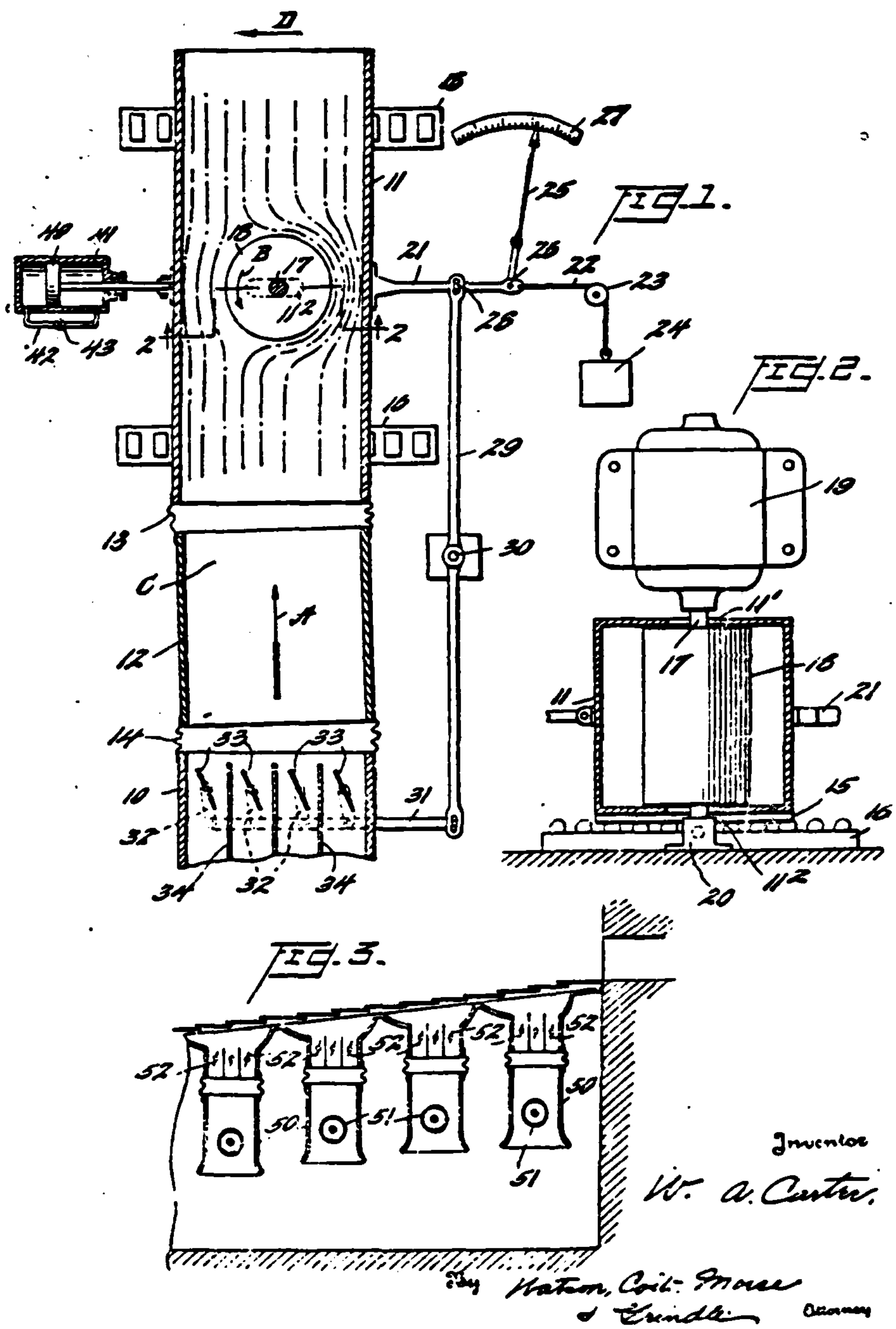
- Figure 6 is a section on line 6-6 of Figure 4.

ASSESSMENT: This invention in a unique use for the Magnus effect but it has little significance within the scope of marine application.

April 27, 1937. W. A. CARTER 2,078,837

MECHANISM FOR UTILIZING THE ENERGY OF A CURRENT OF FLUID

Filed June 27, 1935 2 Sheets-Sheet 1



April 27, 1937. W. A. CARTER 2,078,837

MECHANISM FOR UTILIZING THE ENERGY OF A CURRENT OF FLUID

Filed June 27, 1935 2 Sheets-Sheet 2

FIG. 4.

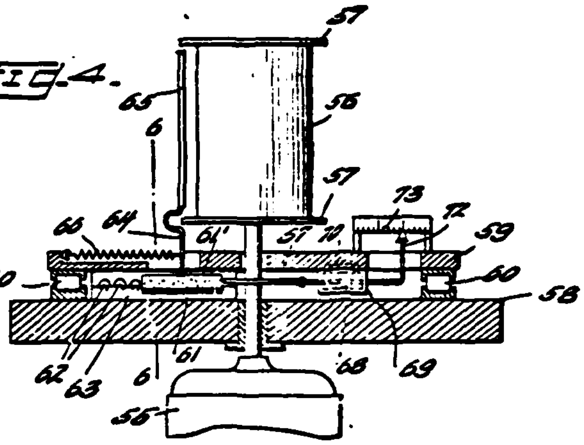


FIG. 5.

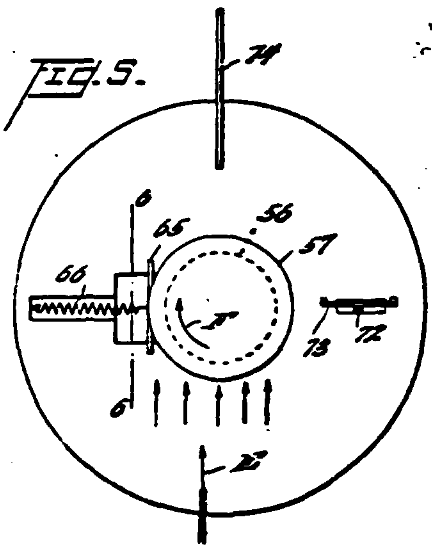
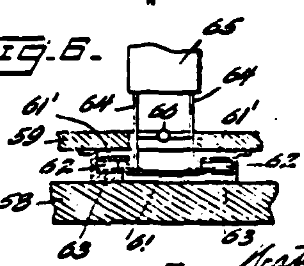


FIG. 6.



Inventor

W. A. Carter

By Watson, Cole, Morse & Grindle, Attorneys

J.E. McDONALD, FAN, U.S. PATENT 2,307,418, ISSUED JANUARY 5, 1943, ASSIGNED TO THE B.F. STURTEVANT COMPANY, BOSTON, MA

The McDonald fan consists of a Magnus effect propeller housed in a nozzle. Five radially positioned, fixed rotors driven by friction wheels are mounted downstream on the fan's shaft. In addition to its use as a means of moving a flow of air, it may be used to straighten out the flow by means of the fixed rotors revolving about the axes in a direction to produce an opposing spin.

- Figure 1 is a sectional view (along line 1-1 of Figure 5) and is a plan view of a partial section looking downward on the propeller fan.
- Figure 2 is a partial end view of the friction driving ring supported from the bearing of Figure 1.
- Figure 3 is a partial view of an alternative autorotor.
- Figure 4 is a view looking downward on the autorotating member.
- Figure 5 is an end view from the left hand or back side of Figure 1.
- Figure 6 is a diagrammatic view illustrating the action of a revolving rotor upon a moving airstream.
- Figure 7 is a vector diagram illustrating the action of the rotor of Figure 6 as an air moving device.

ASSESSMENT: The McDonald fan is significant as the first Magnus effect propeller to be housed in a nozzle which eliminates the drag produced by outboard end plates. It also demonstrates how a spiraling wake may be straightened by using contrarotors. It could be effective in a test facility such as a wind tunnel.

Jan. 5, 1943. J. E. McDONALD 2,307,418

FAN

Filed Nov. 8, 1938 2 Sheets-Sheet 1

Fig. 4

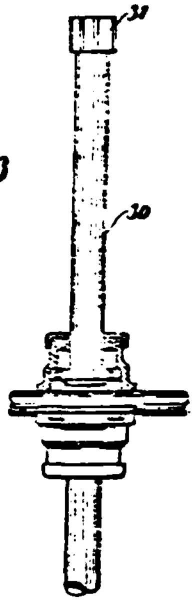


Fig. 3

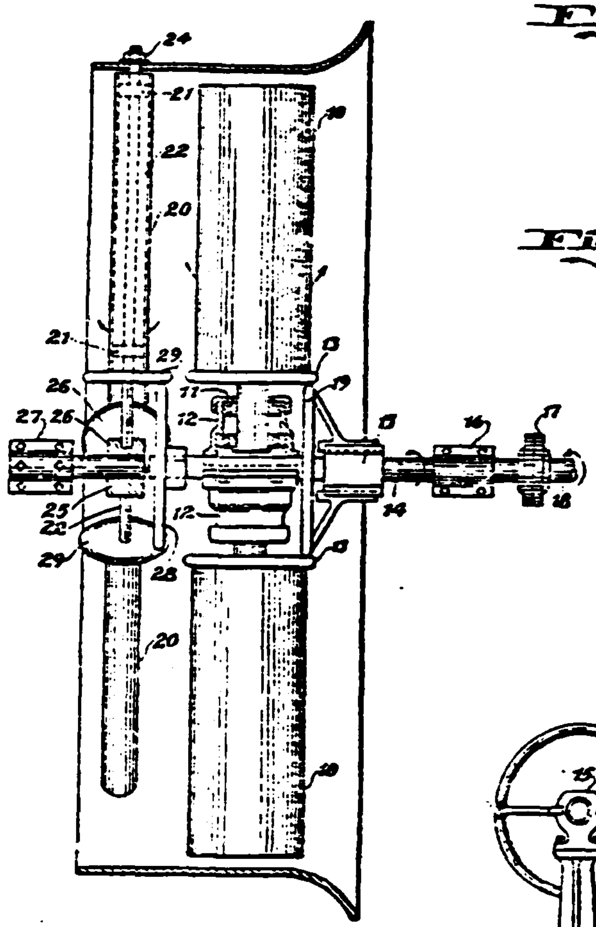


Fig. 1

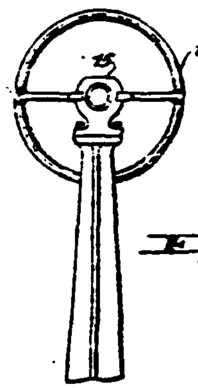


Fig. 2

INVENTOR

JOHN E. McDONALD

BY Robert T. Palmer

ATTORNEY

Jan. 5, 1943. J. E. McDONALD 2,307,418

FAN

Filed Nov. 8, 1939 2 Sheets-Sheet 2

Fig. 5

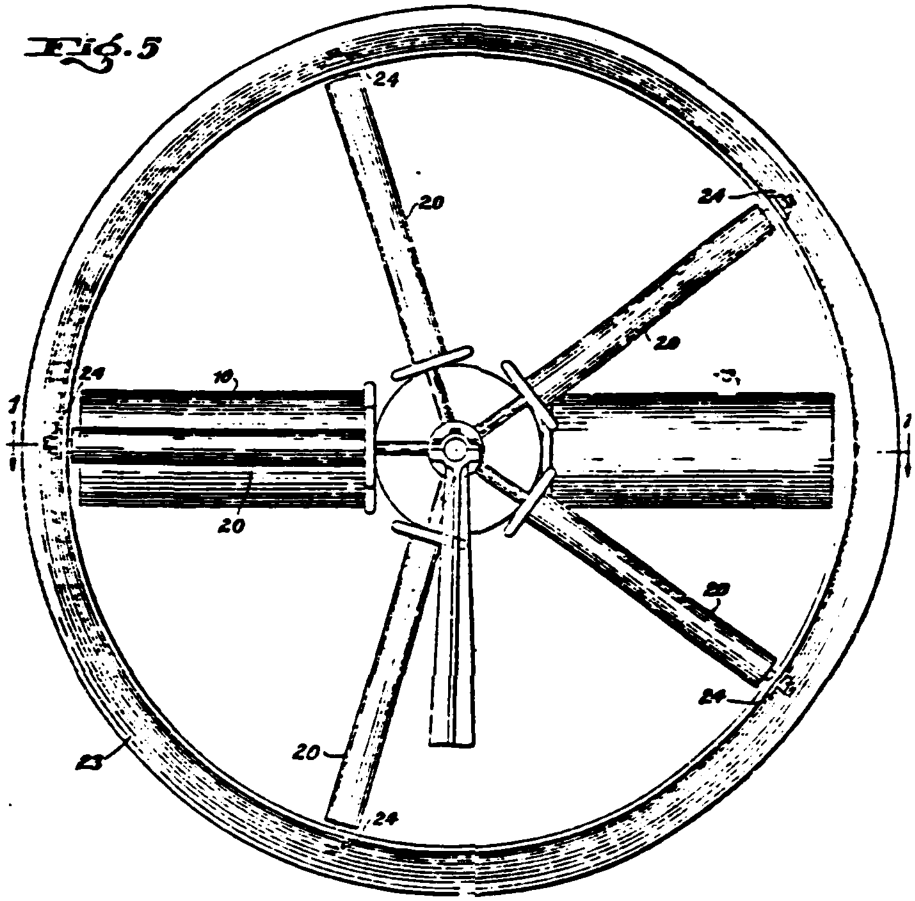


Fig. 6

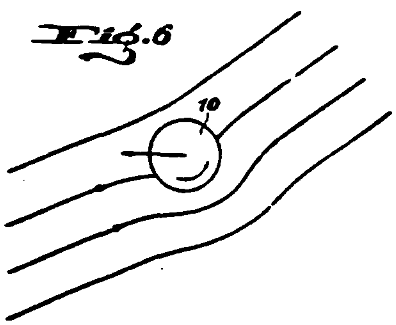
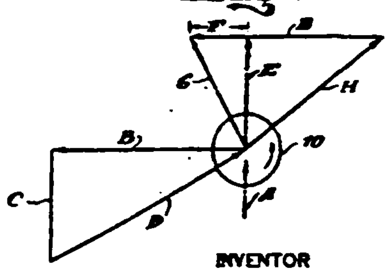


Fig. 7



INVENTOR
John E McDonald
BY Robert J Palmer
ATTORNEY

R. GRAY, APPARATUS FOR GENERATING POWER FROM A FLUID FLOW, U.K. PATENT 2,006,885A, ISSUED AUGUST 12, 1977

Gray's patent includes an impressive number of Magnus effect windmill configurations including ducted rotor propellers, multirotor track systems, and elaborations upon Flettner-type windmills, complete with conical rotors. It is interesting to note that Gray has taken Flettner's coefficient-of-lift curve as exact, claiming a C_L (max) of 9.0. However, other investigators have been able to achieve much higher values.

- Figure 1 shows schematically the Magnus effect.

- Figure 2 is the coefficient of lift curve.

- Figure 3A and 3B respectively show cross-sectional elevations of a turbine in a revolving nozzle, having its rotors impelled by friction wheels running against the surface of a groove located on the inner face of the ring.

- Figure "4A" (reads "4B") shows a detail of the turbine shown in Figures 3A and 3B.

- Figures 5A, 5B and 5C respectively show, an elevation of a cylinder with a tapered airfoil device, a plan of the cylinders on a smaller scale, and an elevation with the airfoil symmetrically arranged.

- Figures 6A and 6B respectively show, schematic elevation and plan views of the turbine windmill of Figure 6A.

- Figure 8A shows an elevation of a modified friction driven windmill.

- Figure 8B shows adjustment of control vanes of the windmill.

- Figures 9A, 9B and 9C respectively show, elevation and plan views of start-up, normal running, and overrunning modes of the windmill of Figure 6A.

- Figure 10 shows a schematic arrangement of the Magnus effect turbine in connection with tapered cylinders.

- Figures 12, 12A, 12B and 12C show details of the Magnus effect turbine.

- Figures 13 and 13A respectively show, upwind elevation and plan views of a low speed windmill having tip mounted air generators.

- Figures 14 and 14A show further arrangements of the windmill of Figures 13 and 13A.

ASSESSMENT: Gray's wind energy converter concepts are so all-encompassing that anyone attempting to use the Magnus effect to produce energy in Great Britain will probably have to pay him a royalty.

G- 2006885
MAY 1979

(12) UK Patent Application (19) GB (11) 2 006 885 A

(21) Application No 7844004
(22) Date of filing 10 Nov 1978
(23) Claims filed 10 Nov 1978
(30) Priority data
(31) 33828/77
(32) 12 Aug 1977
(33) United Kingdom (GB)
(43) Application published
10 May 1979
(51) INT CL²
F03D 5/00 F03B 5/00
(52) Domestic classification
F1T H1B H1X1 W1C
W1X1 W2C3
(56) Documents cited
GB 251624
GB 243756
GB 241739
(58) Field of search
F1T
(71) Applicants
Robert Gray, Little Thatch, Bouldnor, Yarmouth, Isle of Wight
(72) Inventors
Robert Gray
(74) Agents
Edward Evans & Co

(54) Apparatus for Generating Power from Fluid Flow

(57) The apparatus utilises the Magnus effect and comprises, in one arrangement, cylinders rotatable about radial shafts 4 under the action of wind or water flow V passing through a duct supported by arms 5a, the duct itself being rotatable about output shaft 2 by adjustable turbine vanes 20. The cylinders are set in motion by engagement of wheels 8 with a recess 9 in the duct. several modifications are described including one in which the cylinders are carried on an endless belt supported on a pontoon floating in an annular canal for adjustment into the wind.

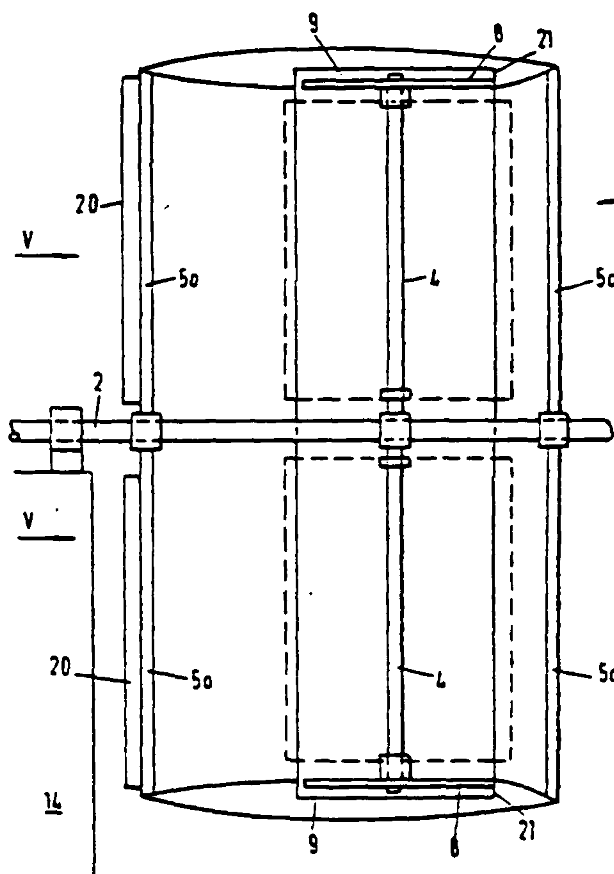


FIG 7

GB 2 006 885 A

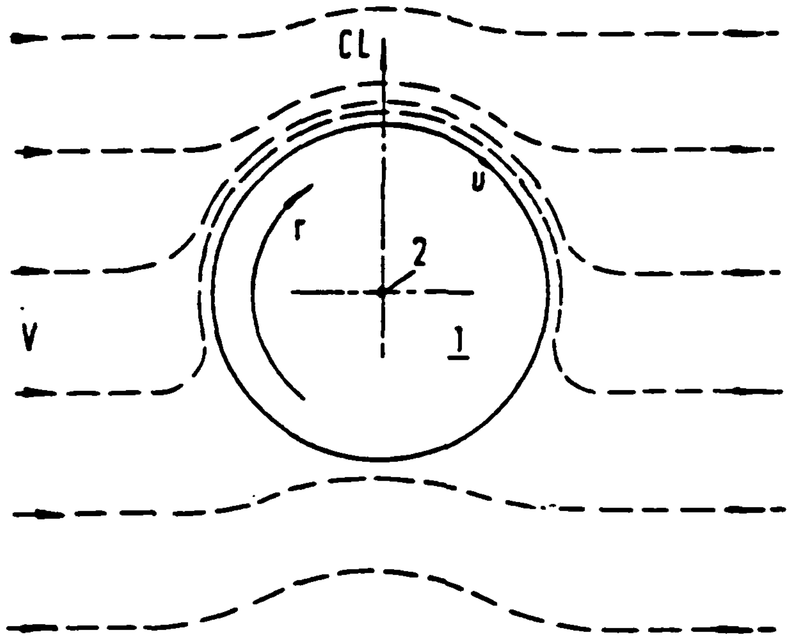
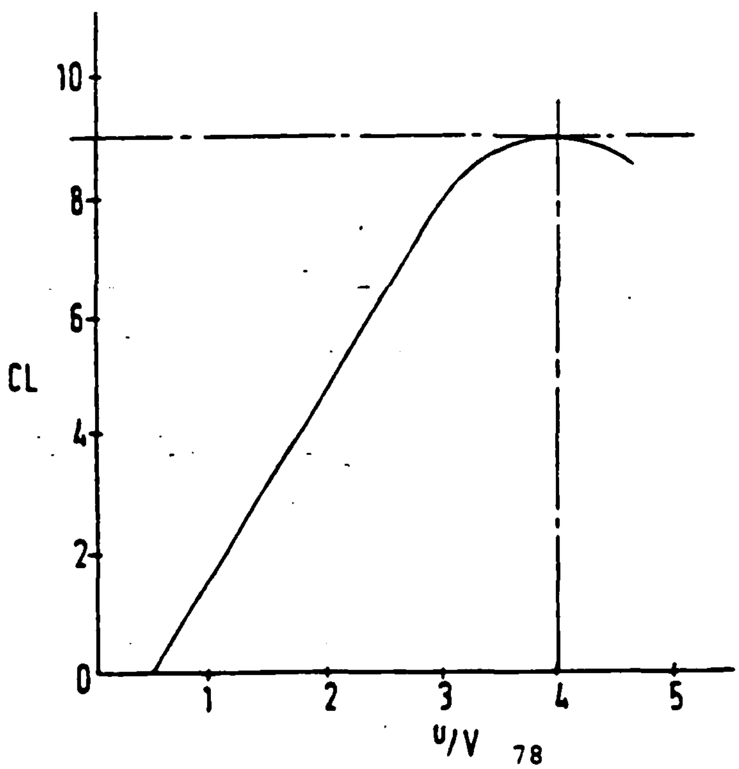


FIG.1.



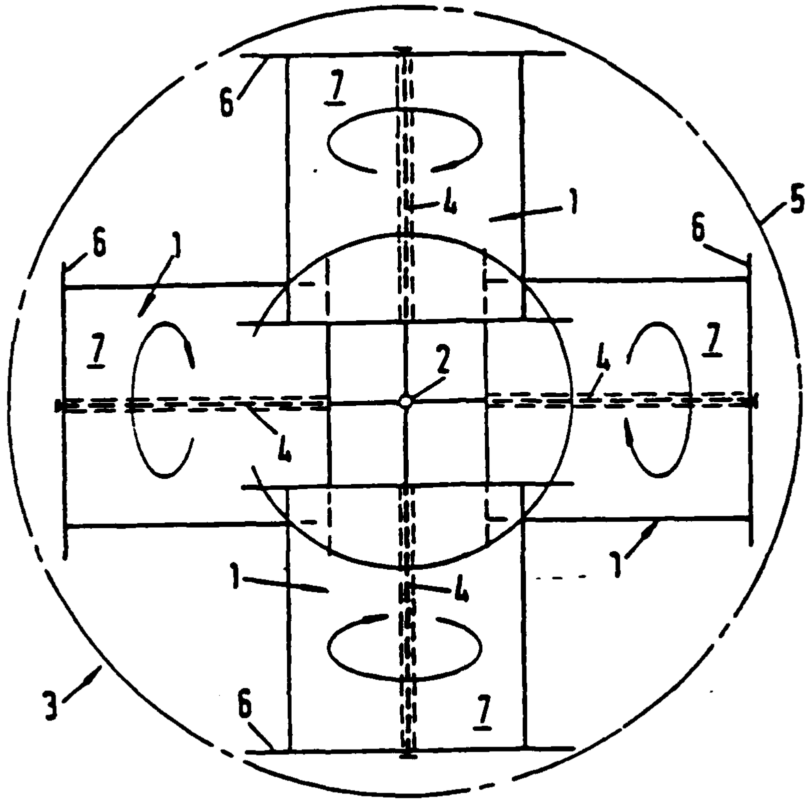


FIG.3A.

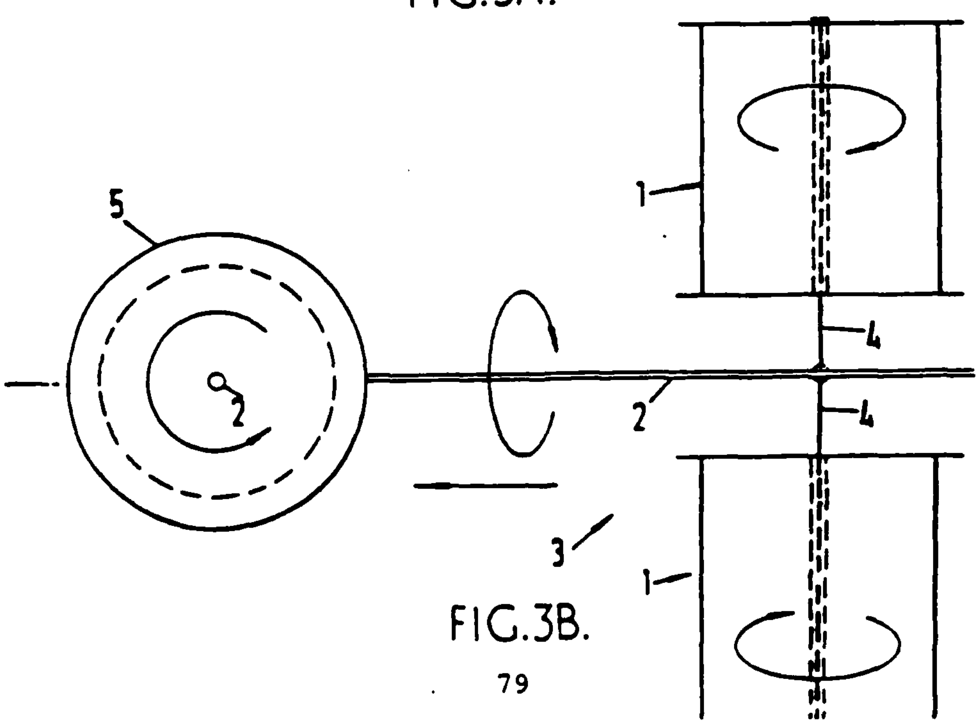


FIG.3B.

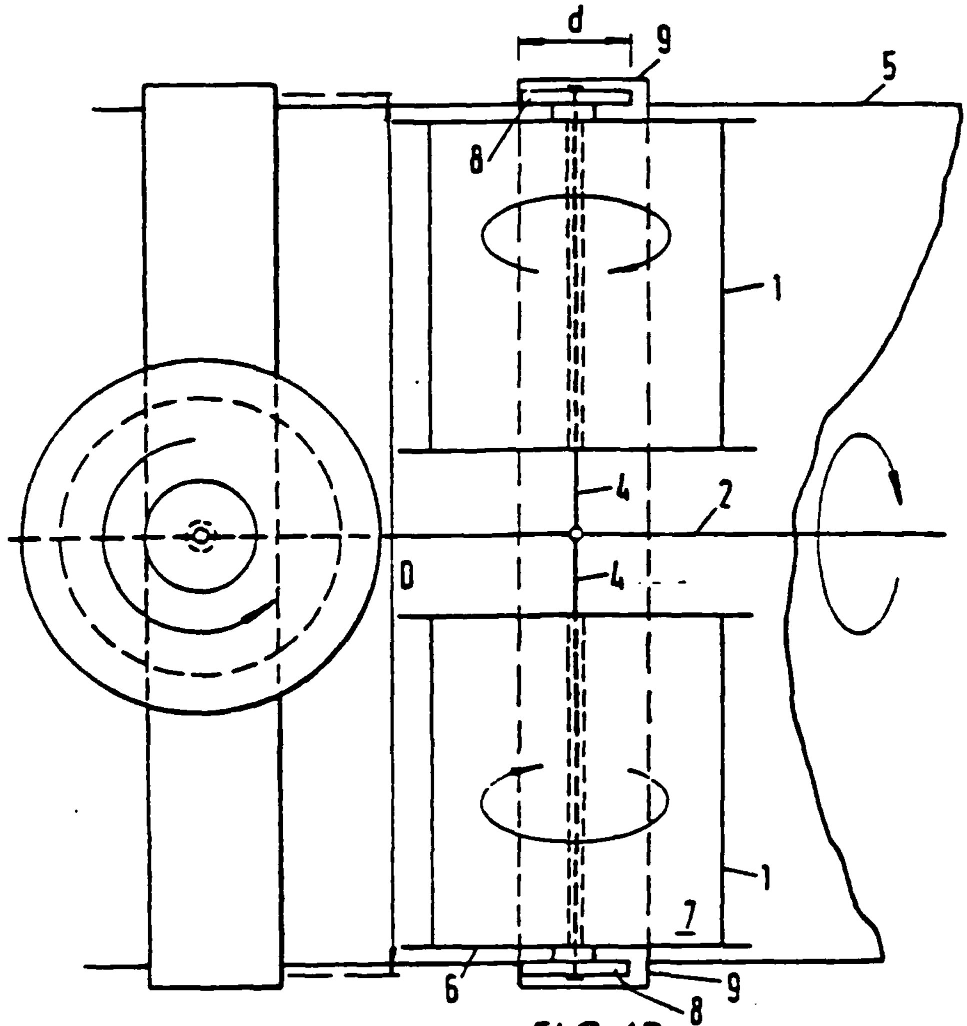


FIG.4B.

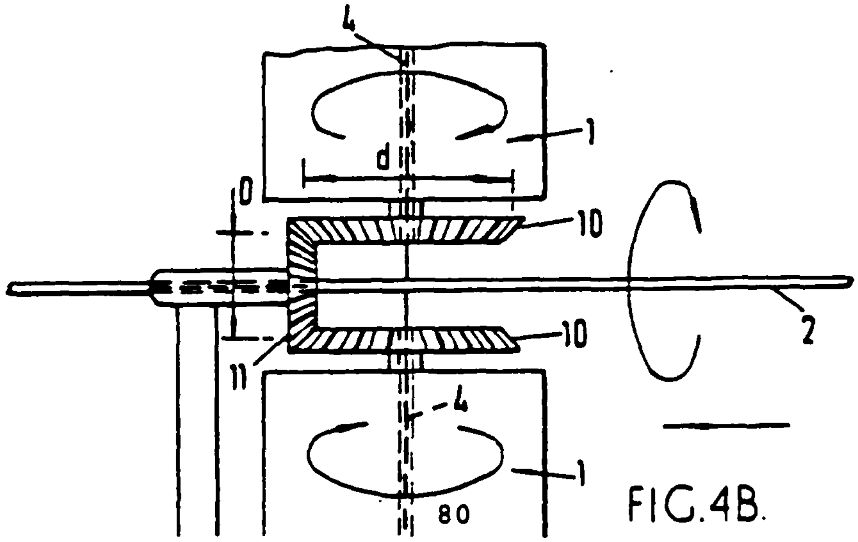


FIG.4B.

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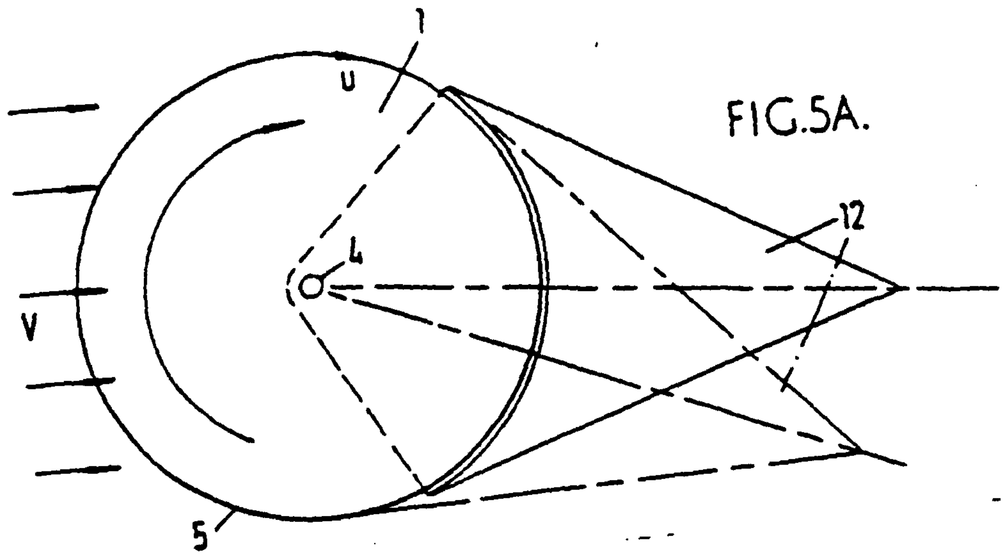


FIG.5A.

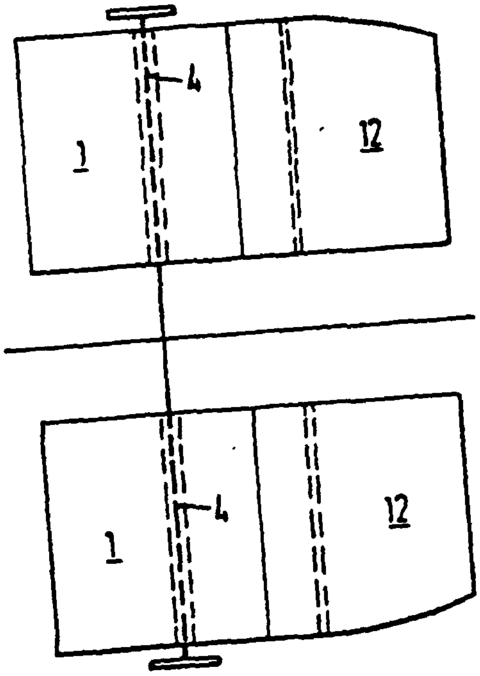


FIG.5B.

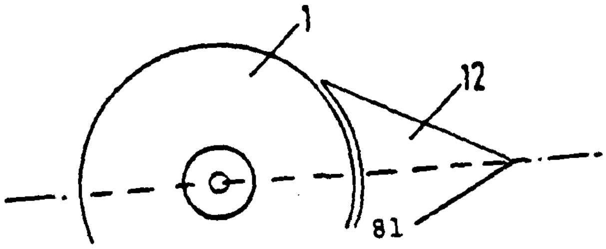


FIG.5C.

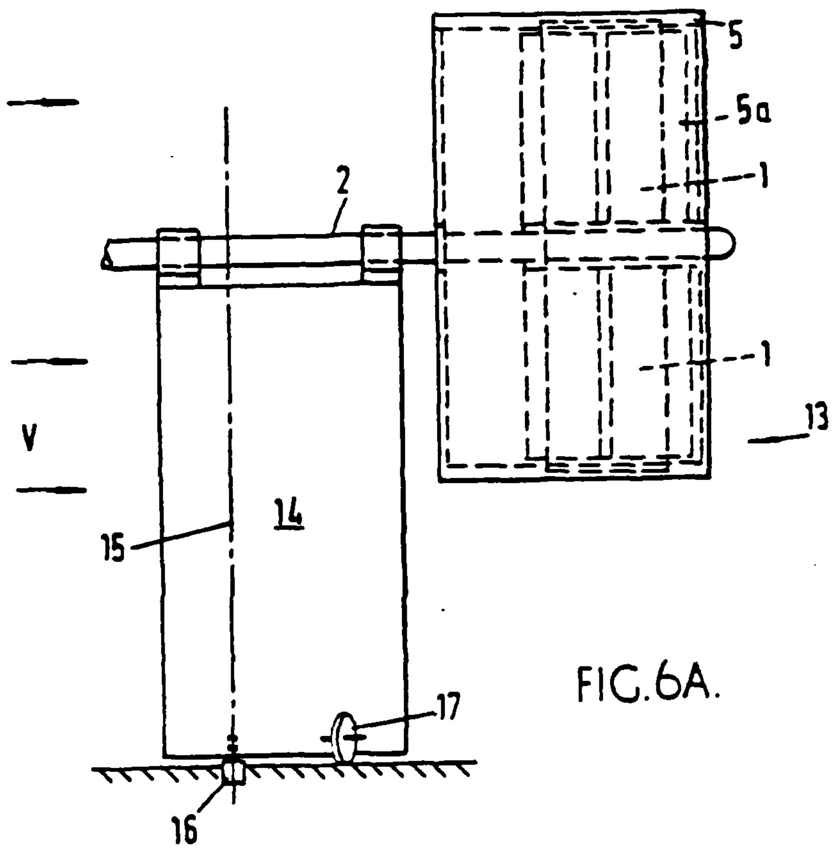


FIG.6A.

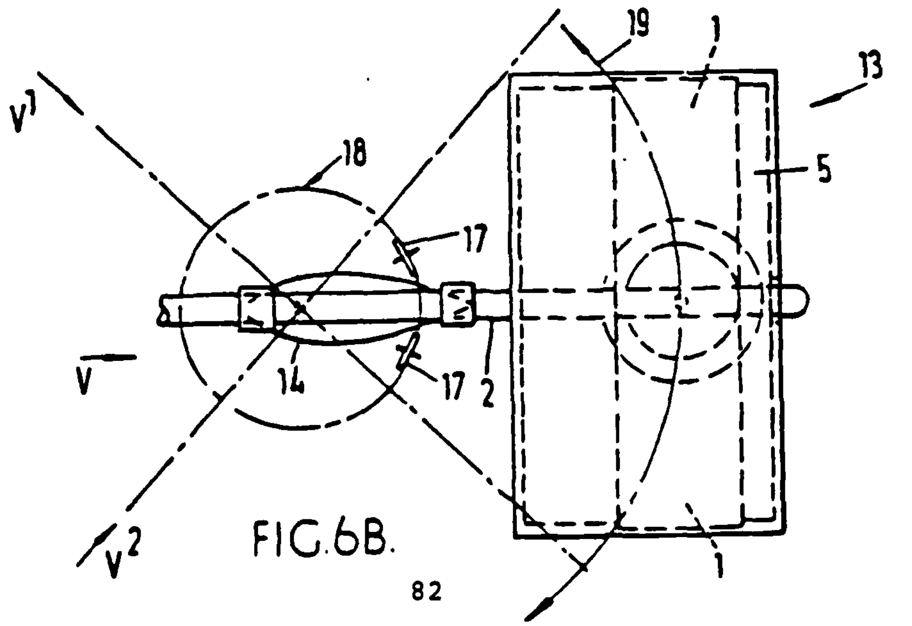


FIG.6B.

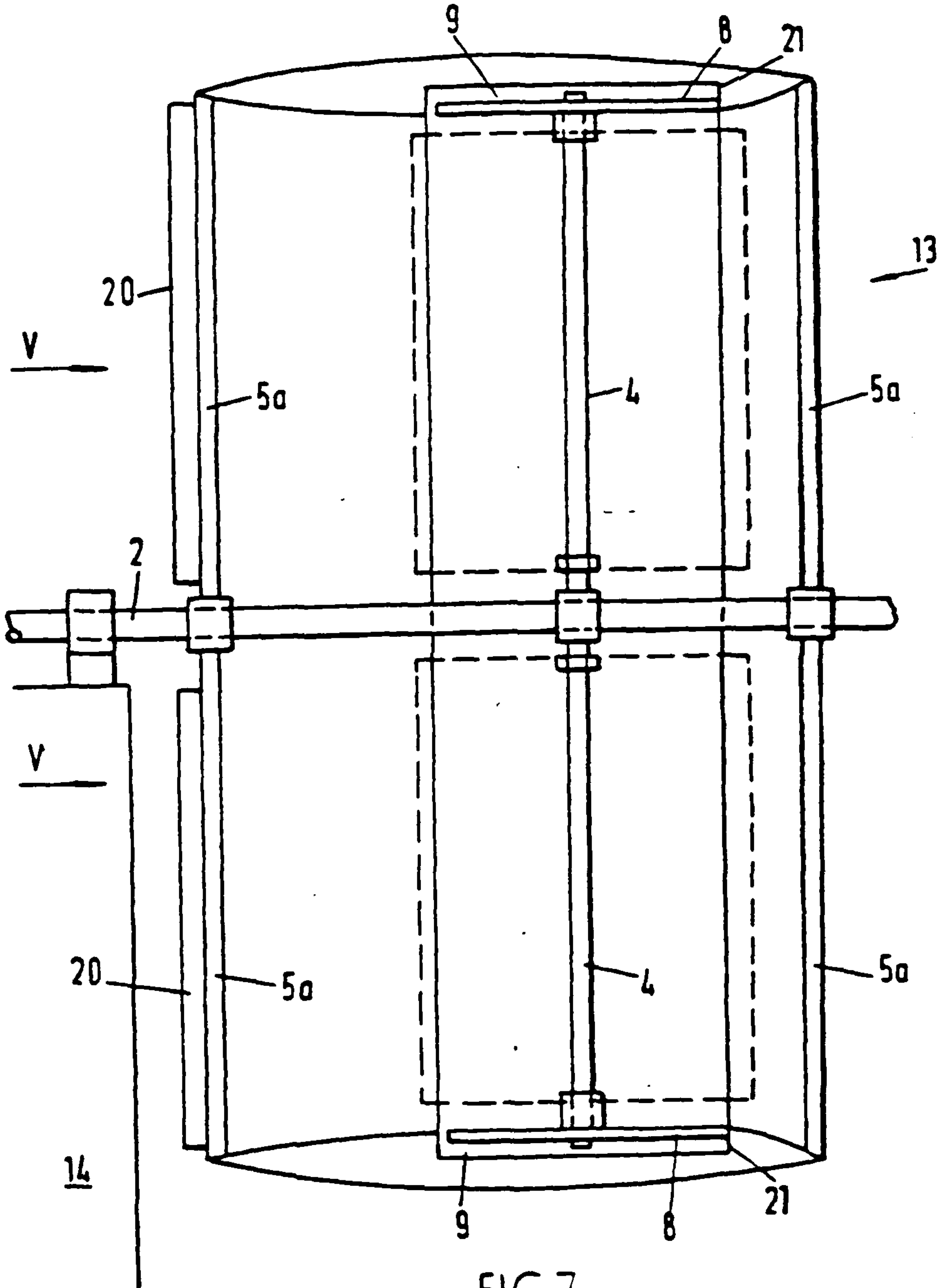


FIG.7.

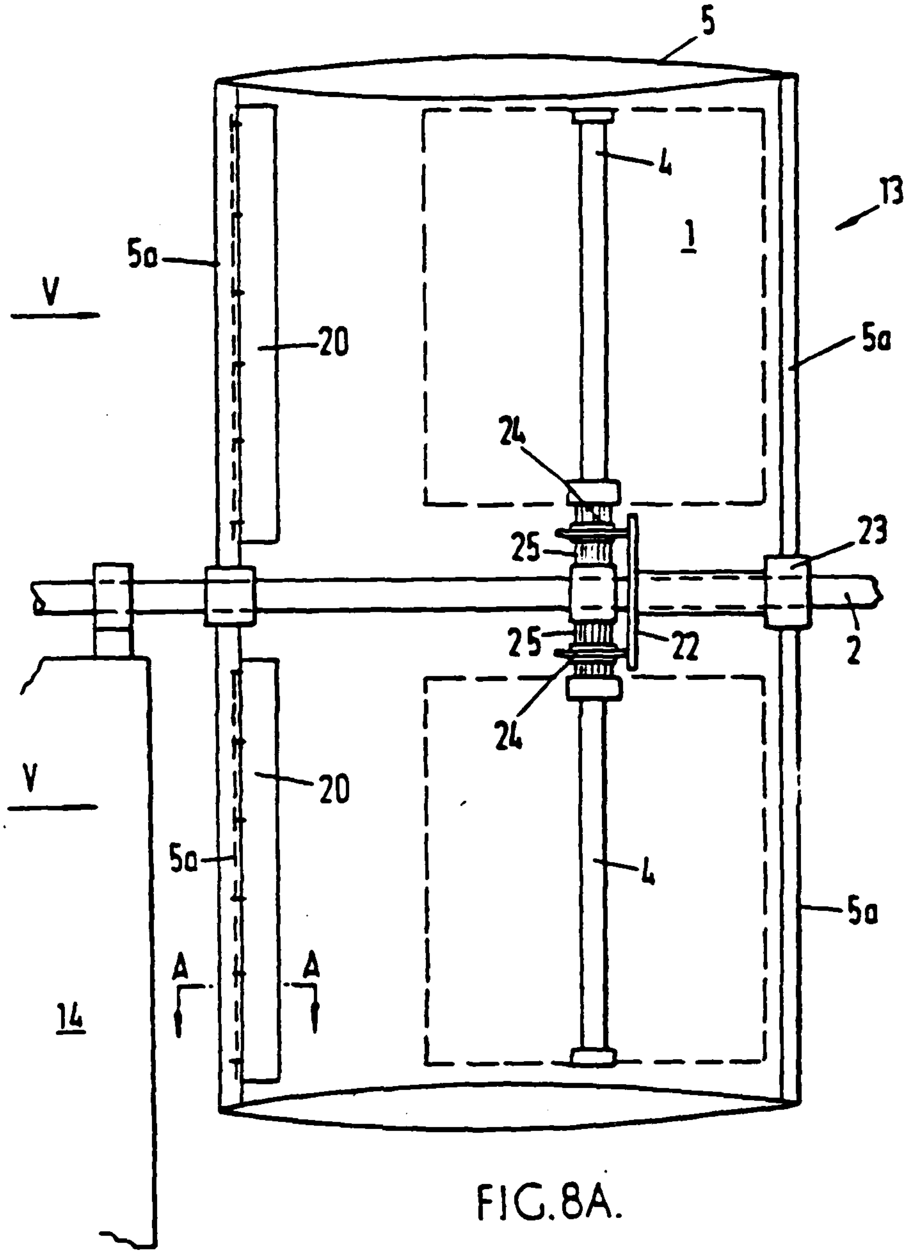
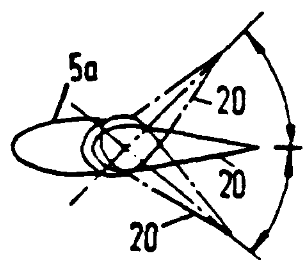


FIG.8A.

FIG.8B.



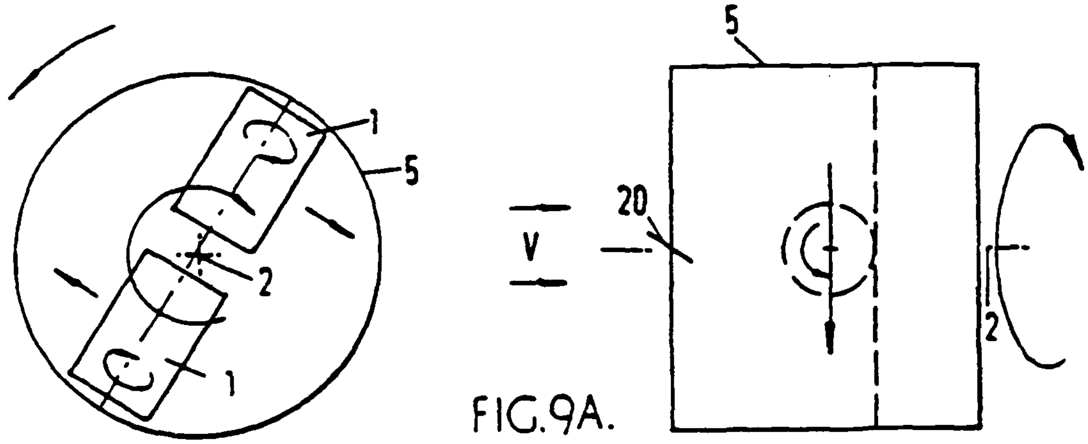


FIG.9A.

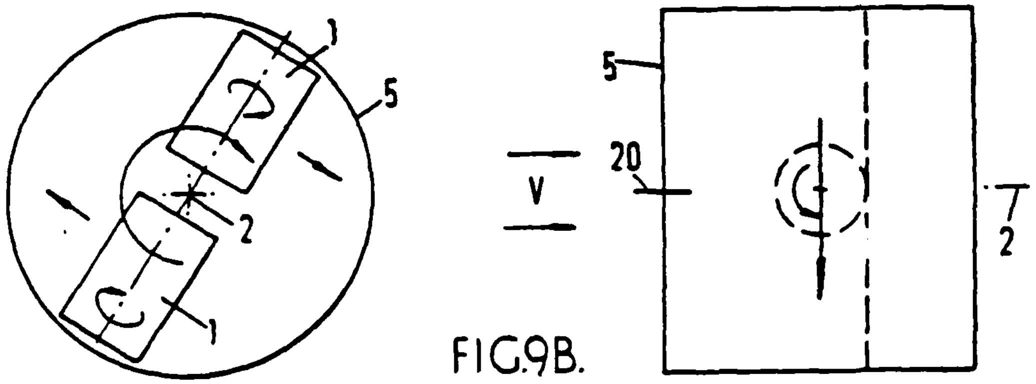


FIG.9B.

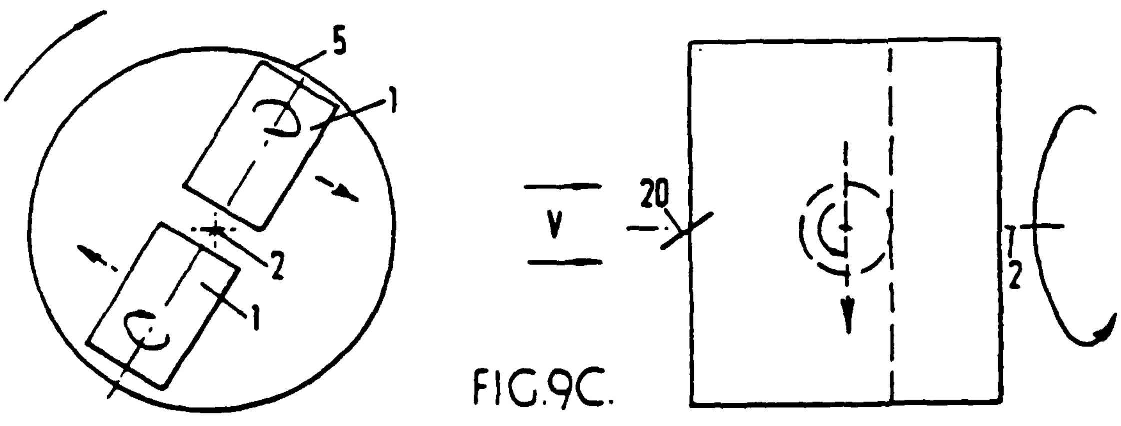


FIG.9C.

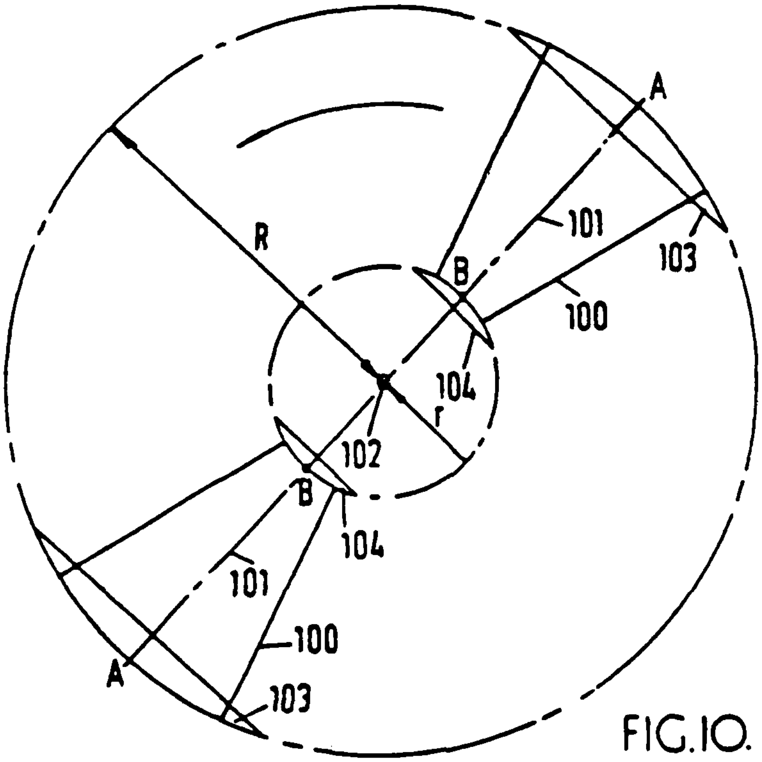


FIG.10.

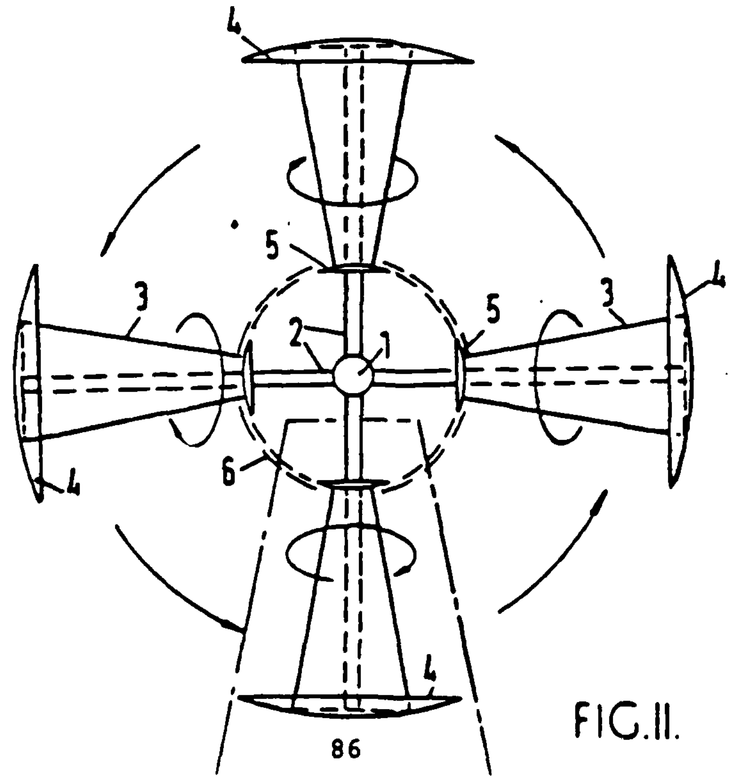


FIG.11.

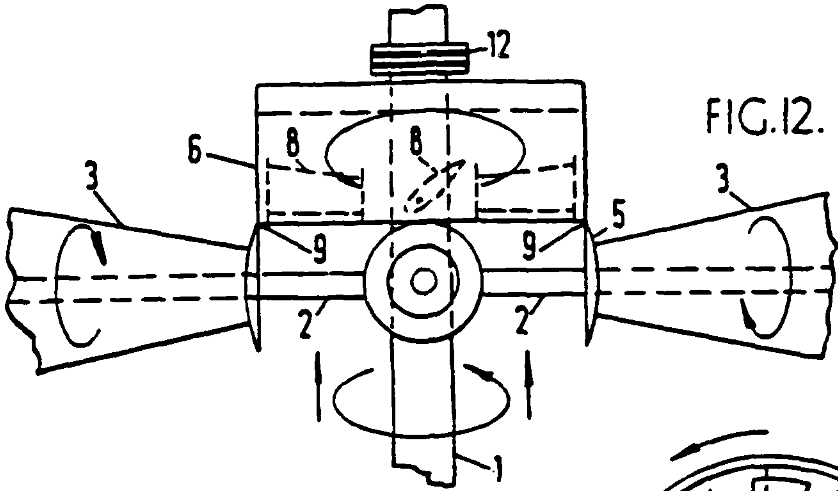


FIG.12.

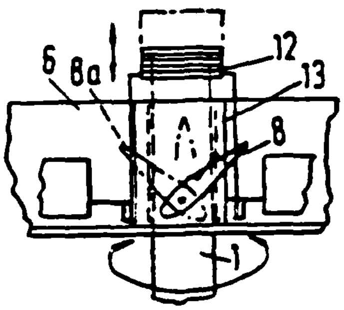


FIG. 12B.

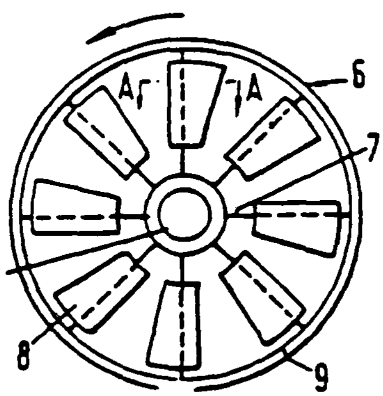


FIG.12A.

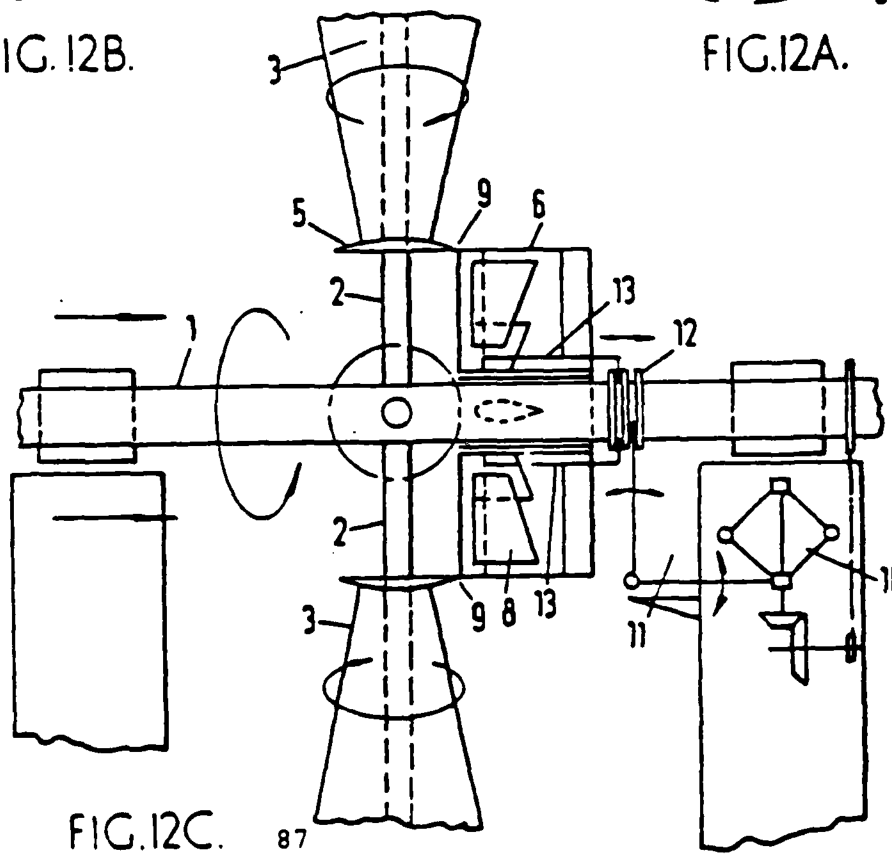


FIG.12C.

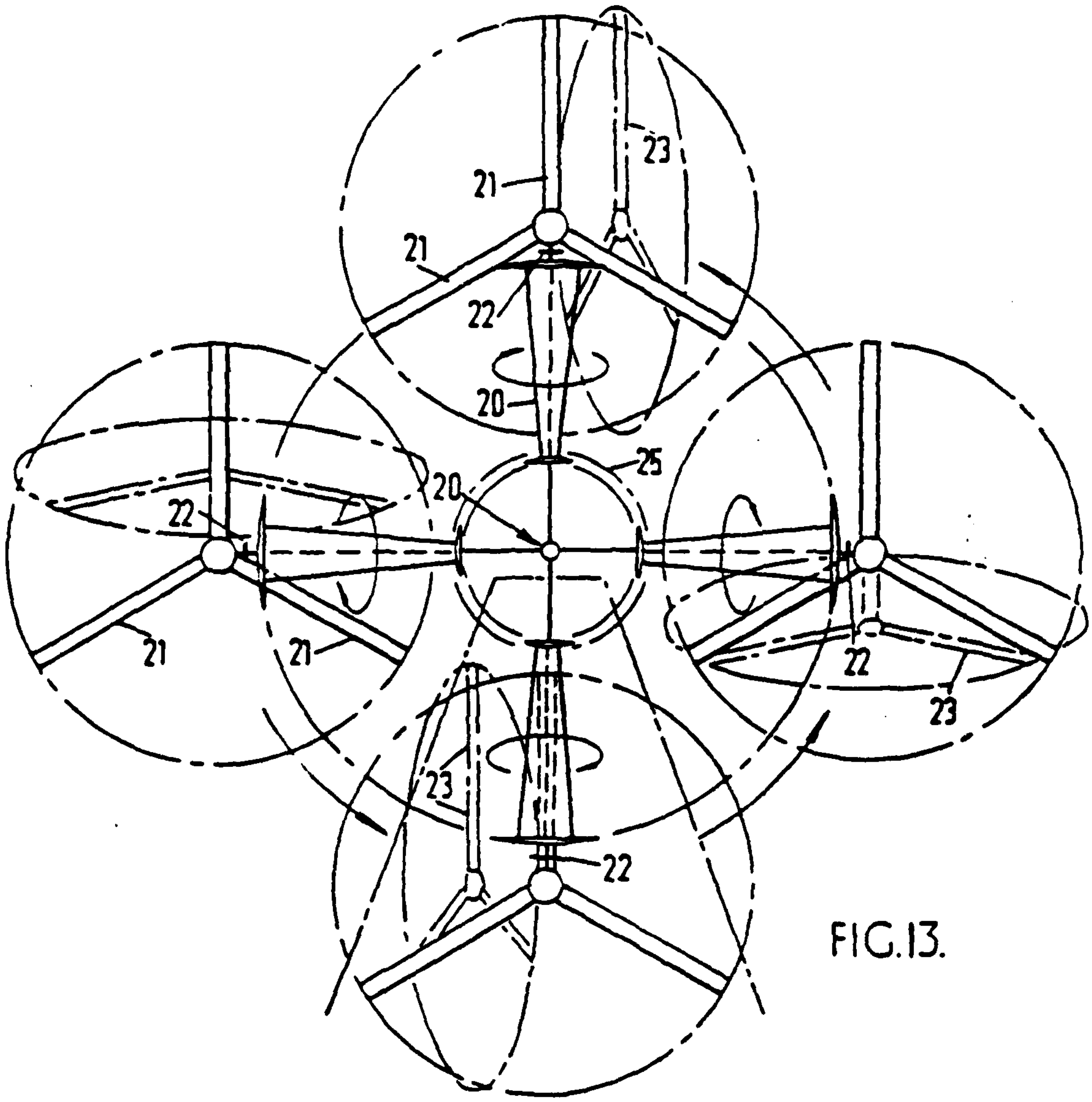
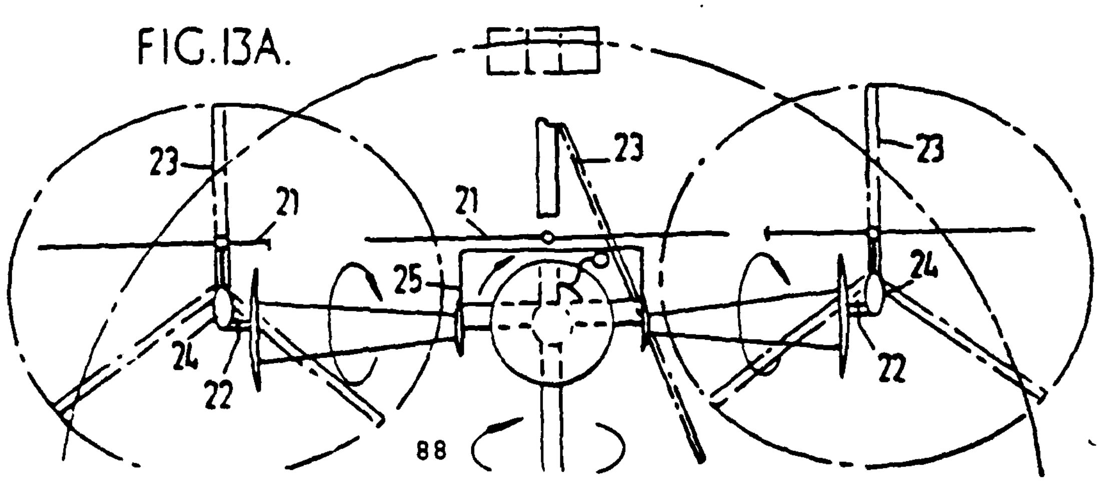


FIG.13.

FIG.13A.



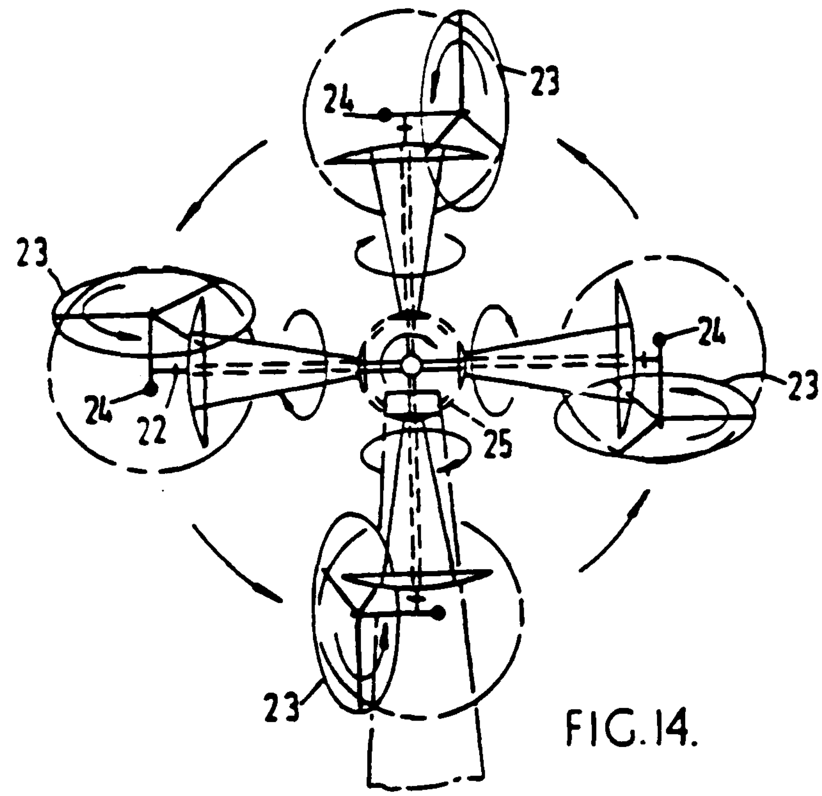


FIG.14.

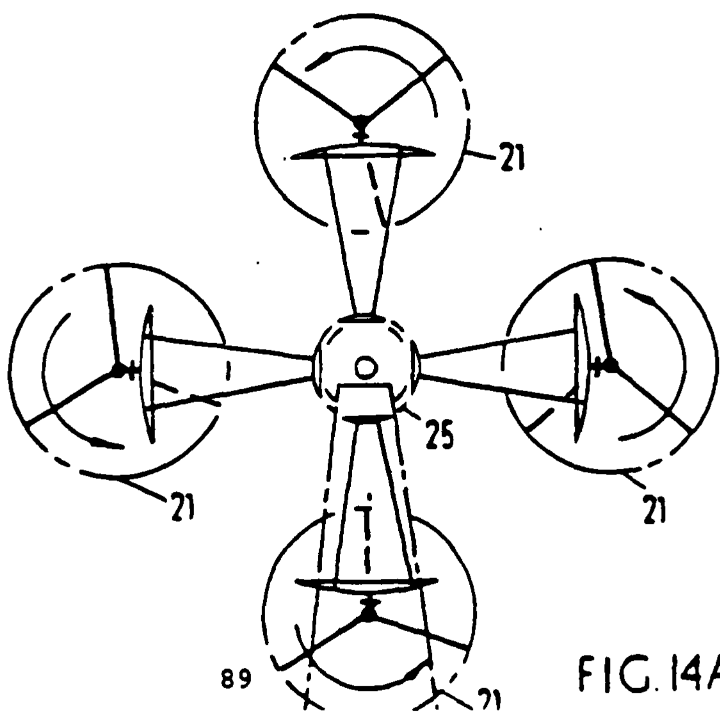


FIG.14A.

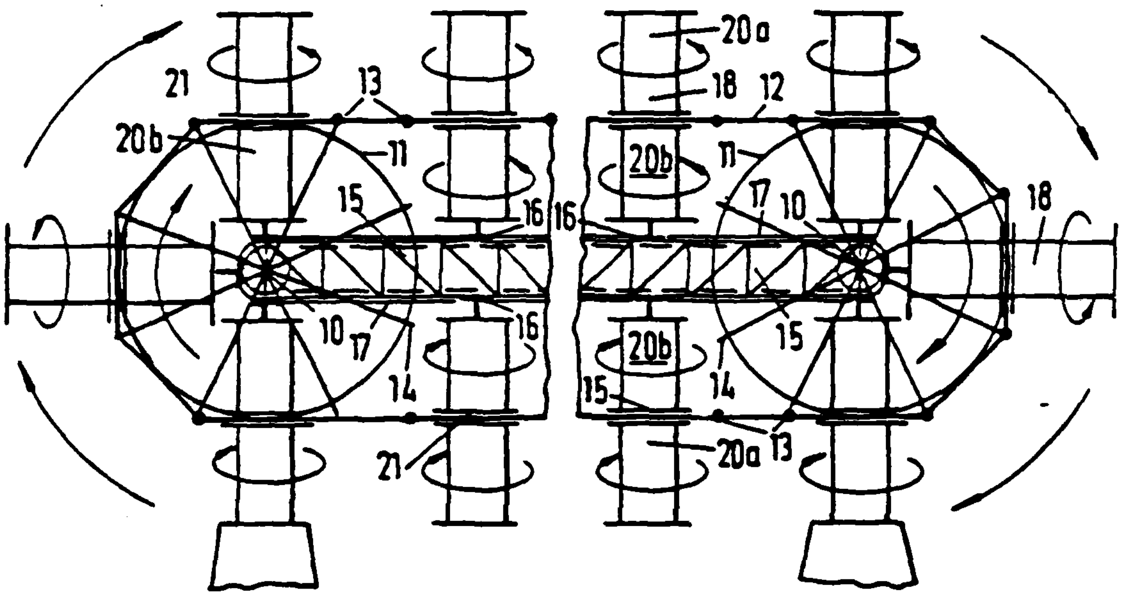


FIG. 15.

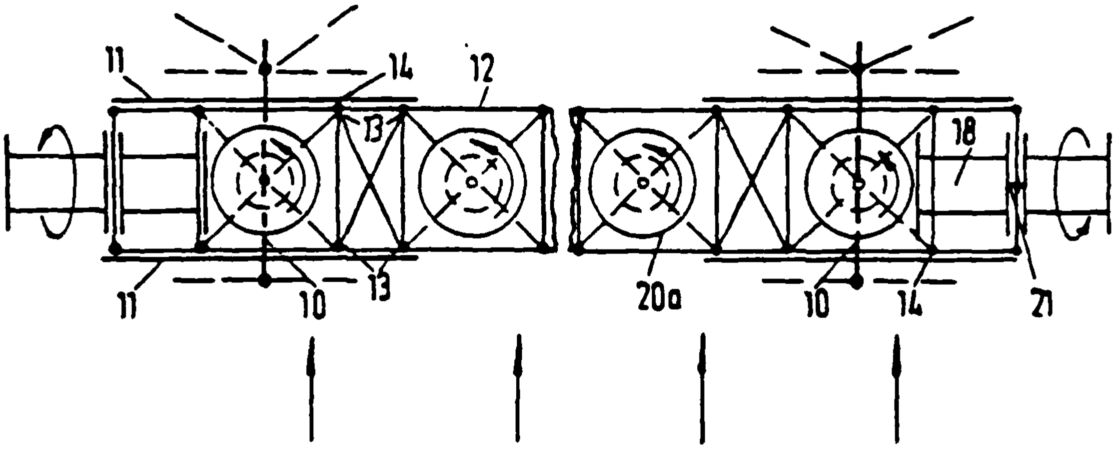


FIG. 15A.

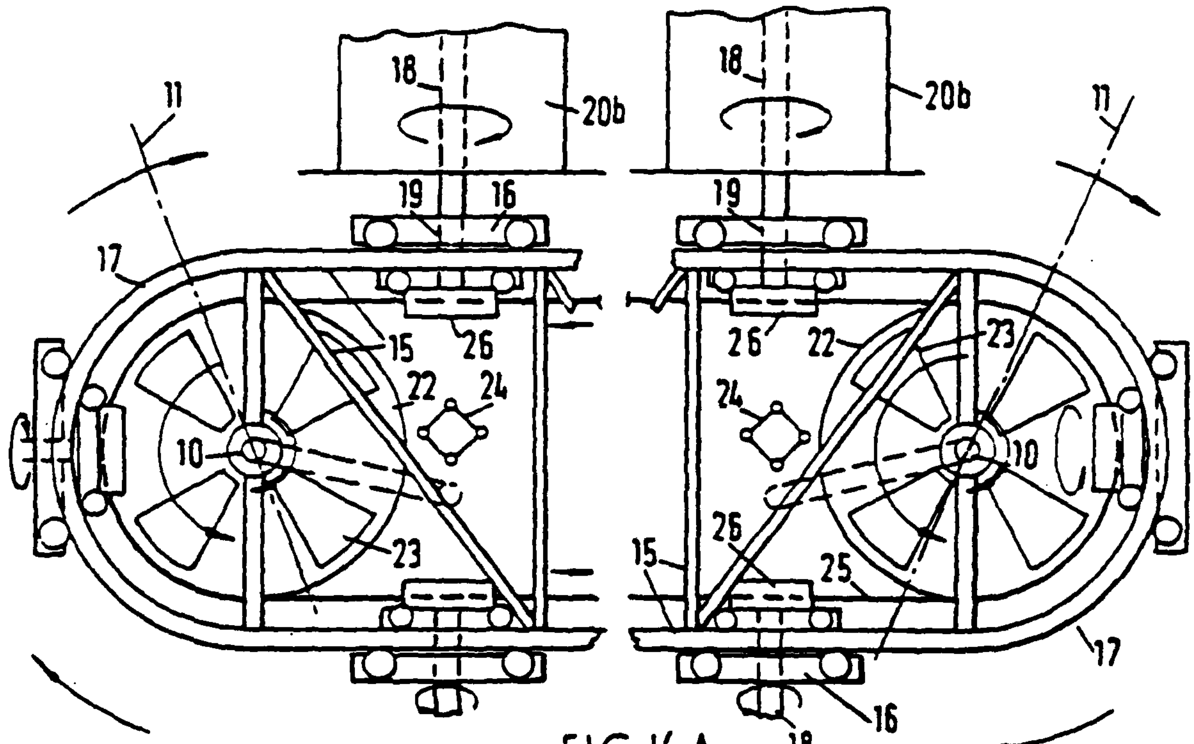

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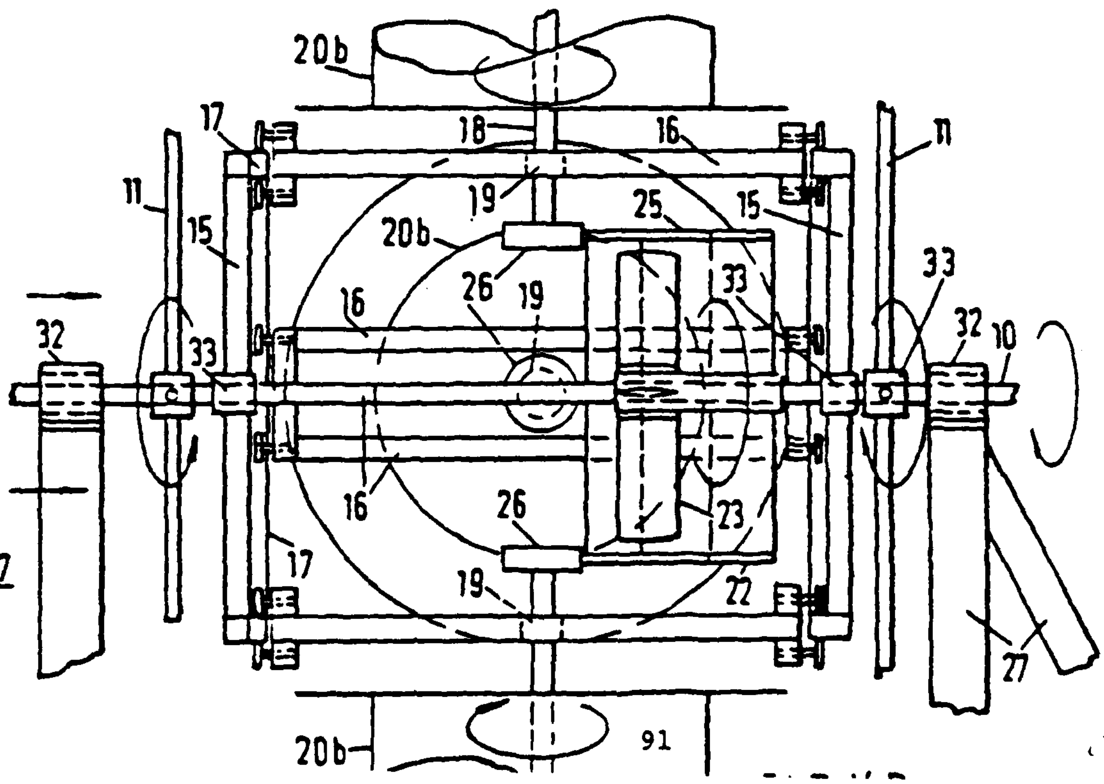
FIG.16A.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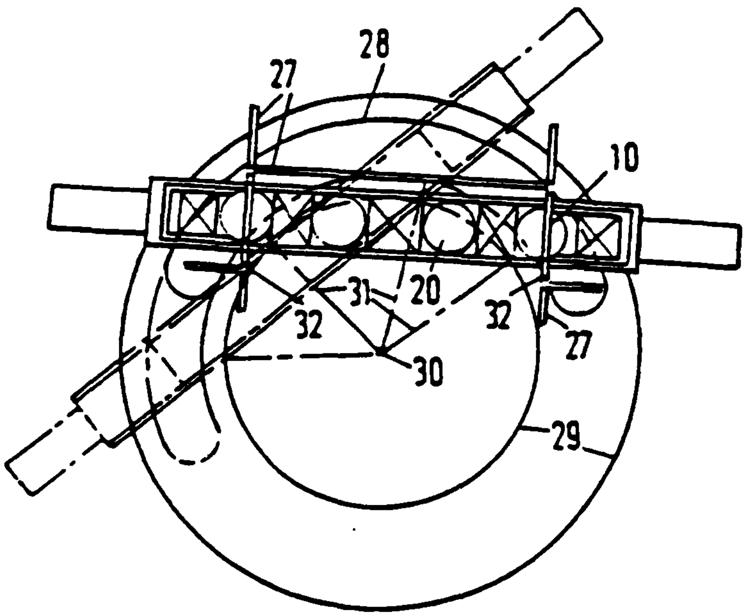
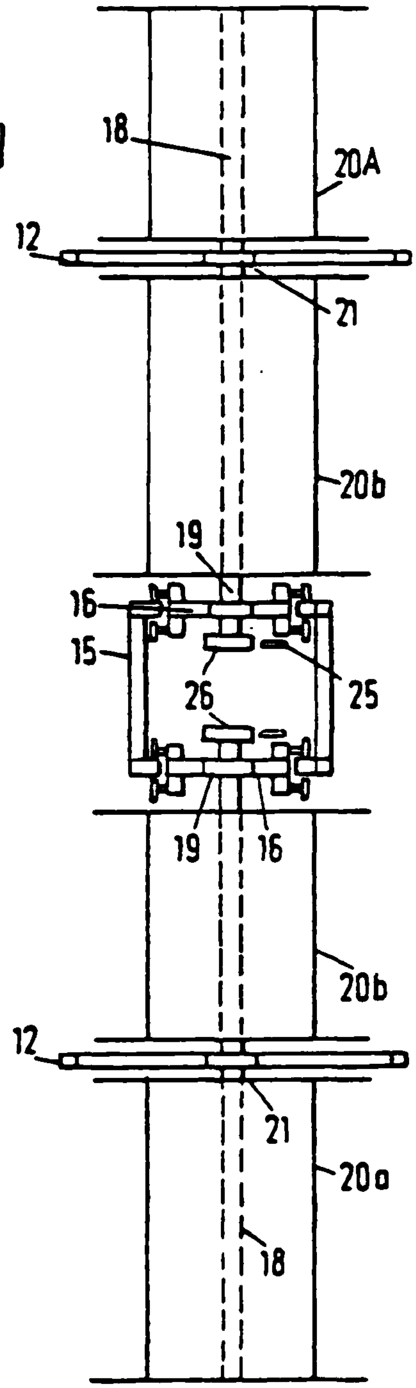


FIG. 17A.



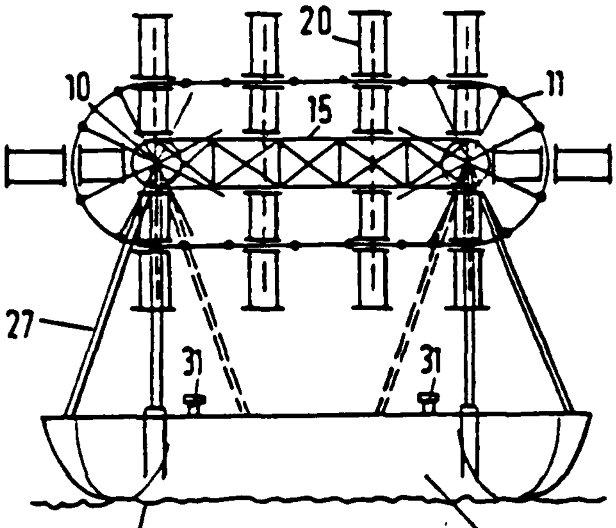


FIG 17B.

FIG. 17.

T.F. HANSON, MAGNUS AIR TURBINE SYSTEM, U.S. PATENT 4,366,386, ISSUED DECEMBER 28, 1982

The Hanson patent is an updated version of the Flettner windmill and represents a milestone in Magnus effect technology. Notably, the system uses modern materials and aerospace engineering techniques and the machine's internal mechanical arrangement provides energy to spin the rotors automatically once the unit has been started. A full-sized prototype of the turbine has been constructed and successfully tested.

- Figure 1 is a side elevation view of the air turbine.

- Figure 2 is a rear view of the turbine.

- Figure 3 is an enlarged view of the major subassemblies. Note that the rotor structure is unique in that only the surface of the barrel revolves and the forces are absorbed through a mastlike structure.

- Figure 4 is an enlarged cutaway view of a portion of the nacelle and rotor. The windward end of the assembly is pivoted on the support mast so that it will orient itself with the wind direction.

- Figure 5 is a cross-sectional view of the structure taken along lines 5-5 of Figure 4. Figure 6 is a cross-sectional view of a portion of the structure of Figure 4 taken along lines 6-6.

- Figure 7 is a partially sectioned, partially cutaway view of a variable speed drive, load integrator and regulator apparatus.

- Figure 8 is a side view of Figure 7.

- Figure 9 is a partially sectioned, partially cutaway view of the gear train system for removing power from the turbine, collecting it and spinning the Magnus barrels.

- Figure 10 is a cross-sectional view of a portion of Figure 9 taken along lines 10-10.

- Figure 11 is a graph, plotting output power, showing 900 horsepower in winds of 60 miles per hour.

- Figure 12 is a side elevation of the structure illustrating its initial erection.

ASSESSMENT: The inventor achieved his objectives of a light-weight, low-cost per kilowatt hour, storm-proof wind turbine with this design. A duplicate of the machine could probably be produced from the lucid patent description.

United States Patent [19]

Hanson

[11] **4,366,386**

[45] **Dec. 28, 1982**

[54] **MAGNUS AIR TURBINE SYSTEM**

[76] Inventor: **Thomas F. Hanson**, 24204 Heritage La., Newhall, Calif. 91321

[21] Appl. No.: **262,136**

[22] Filed: **May 11, 1981**

[51] **Int. Cl.**^{3} **F03B 5/00**; F03D 7/06; H02P 9/04

[52] **U.S. Cl.** **290/44**; 290/55; 416/4

[58] **Field of Search** 290/43, 44, 54, 55; 416/4

[56] **References Cited**

FOREIGN PATENT DOCUMENTS

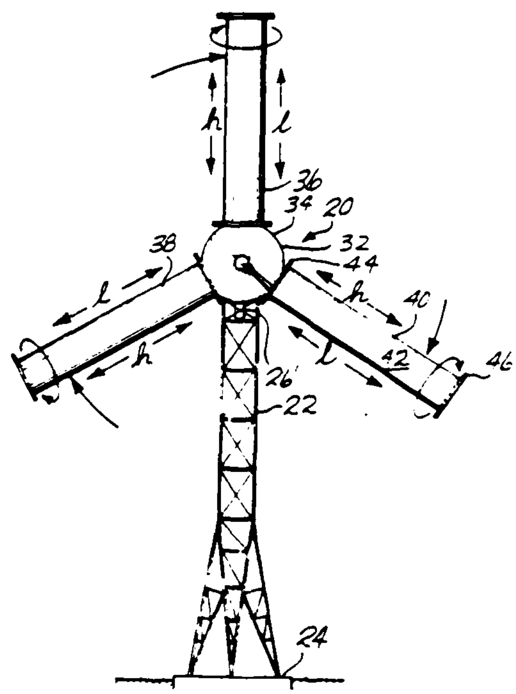
250636 4/1926 United Kingdom 416/4

Primary Examiner—J. V. Truhe
Assistant Examiner—Shelley Wade
Attorney, Agent, or Firm—Daniel T. Anderson

[57] **ABSTRACT**

A Magnus effect windmill for generating electrical power is disclosed. A large nacelle-hub mounted pivotally (in Azimuth) atop a support tower carries, in the example disclosed, three elongated barrels arranged in a vertical plane and extending symmetrically radially outwardly from the nacelle. The system provides spin energy to the barrels by internal mechanical coupling in the proper sense to cause, in reaction to an incident wind, a rotational torque of a predetermined sense on the hub. The rotating hub carries a set of power take-off rollers which ride on a stationary circular track in the nacelle. Shafts carry the power, given to the rollers by the wind driven hub, to a central collector or accumulator gear assembly whose output is divided to drive the spin mechanism for the Magnus barrels and the main electric generator. A planetary gear assembly is interposed between the collector gears and the spin mechanism functioning as a differential which is also connected to an auxiliary electric motor whereby power to the spin mechanism may selectively be provided by the motor. Generally, the motor provides initial spin to the barrels for start-up after which the motor is braked and the spin mechanism is driven as though by a fixed ratio coupling from the rotor hub. During high wind or other unusual conditions, the auxiliary motor may be unbraked and excess spin power may be used to operate the motor as a generator of additional electrical output. Interposed between the collector gears of the rotating hub and the main electric generator is a novel variable speed drive-fly wheel system which is driven by the variable speed of the wind driven rotor and which, in turn, drives the main electric generator at constant angular speed. Reference is made to the complete specification for disclosure of other novel aspects of the system such as, for example, the aerodynamic and structural aspects of the novel Magnus barrels as well as novel gearing and other power coupling combination apparatus of the invention. A reading of the complete specification is recommended for a full understanding of the principles and features of the disclosed system.

13 Claims, 12 Drawing Figures



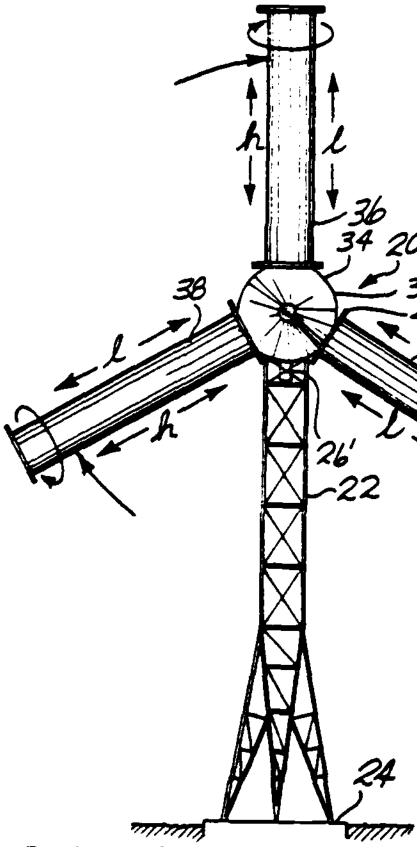


Fig.2

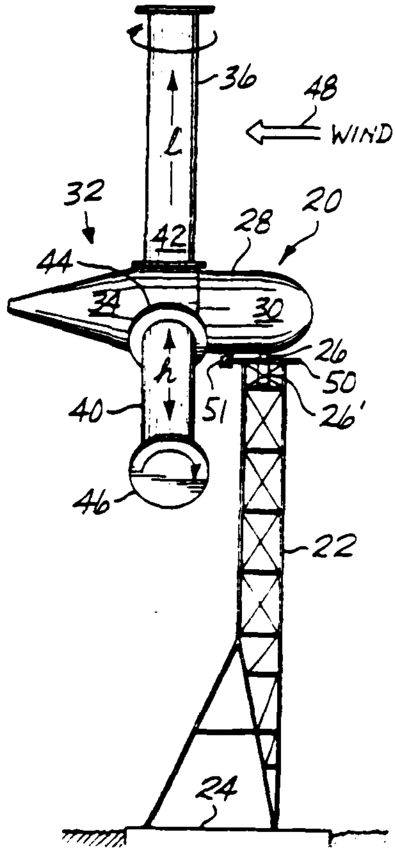


Fig.1

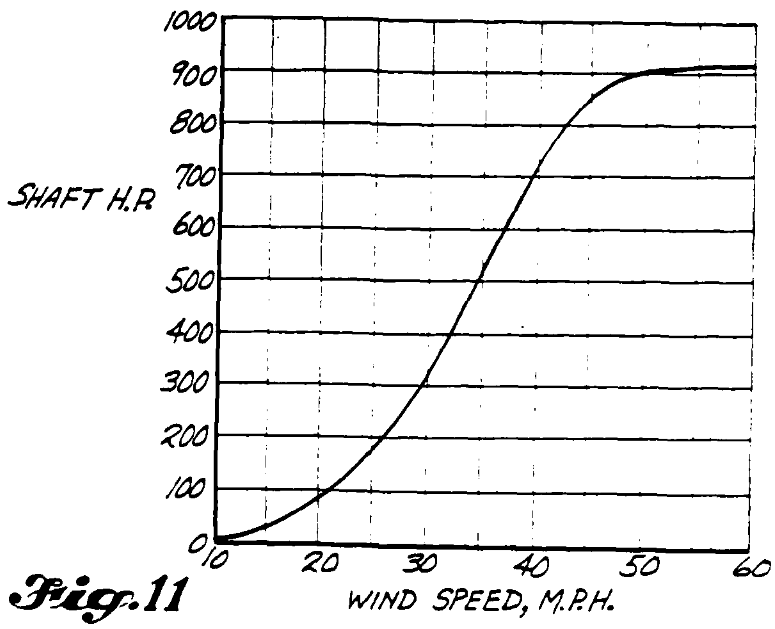


Fig.11

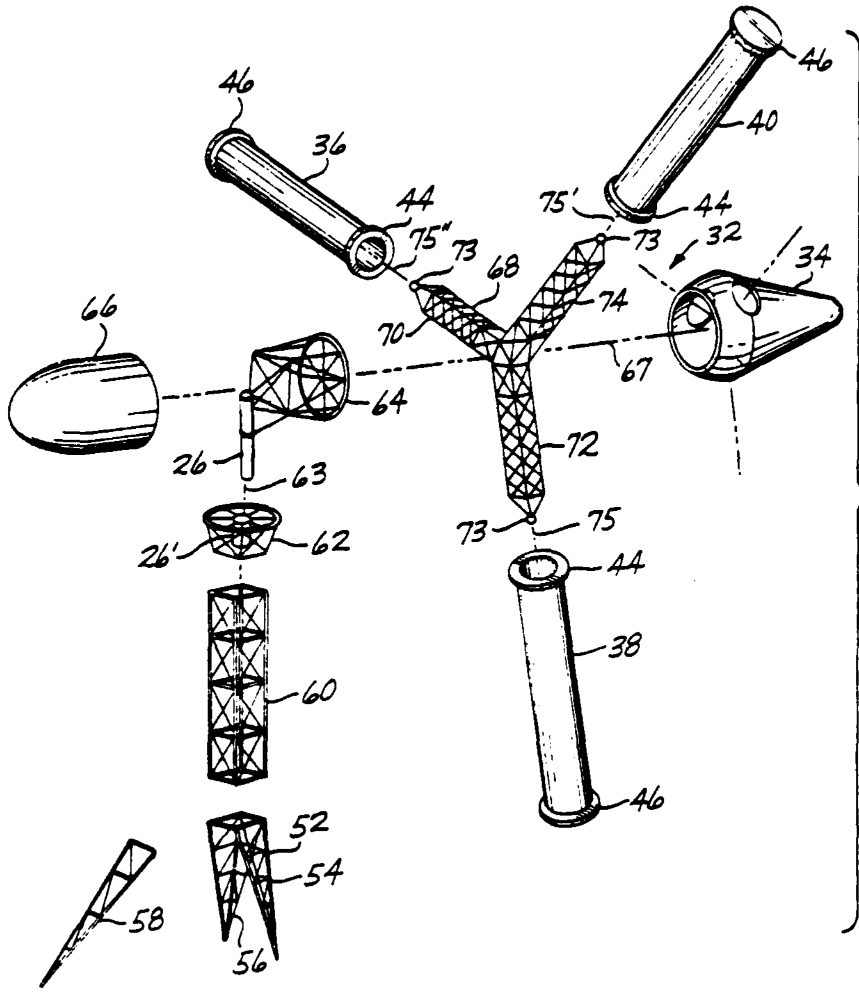


Fig. 3

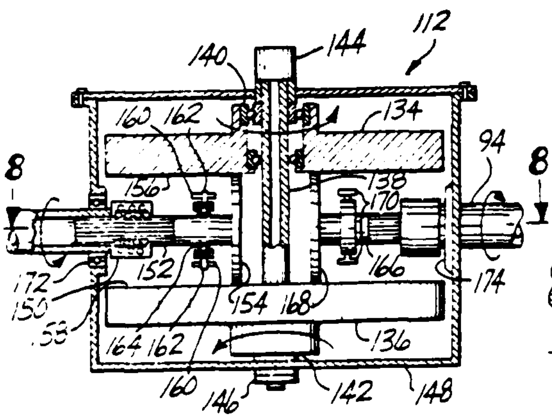


Fig. 7

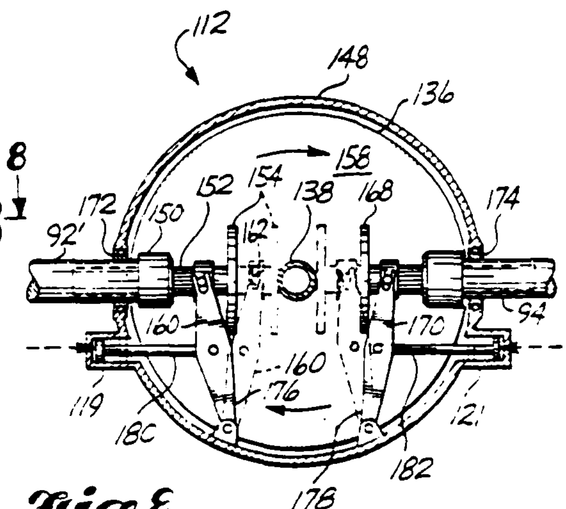


Fig. 8

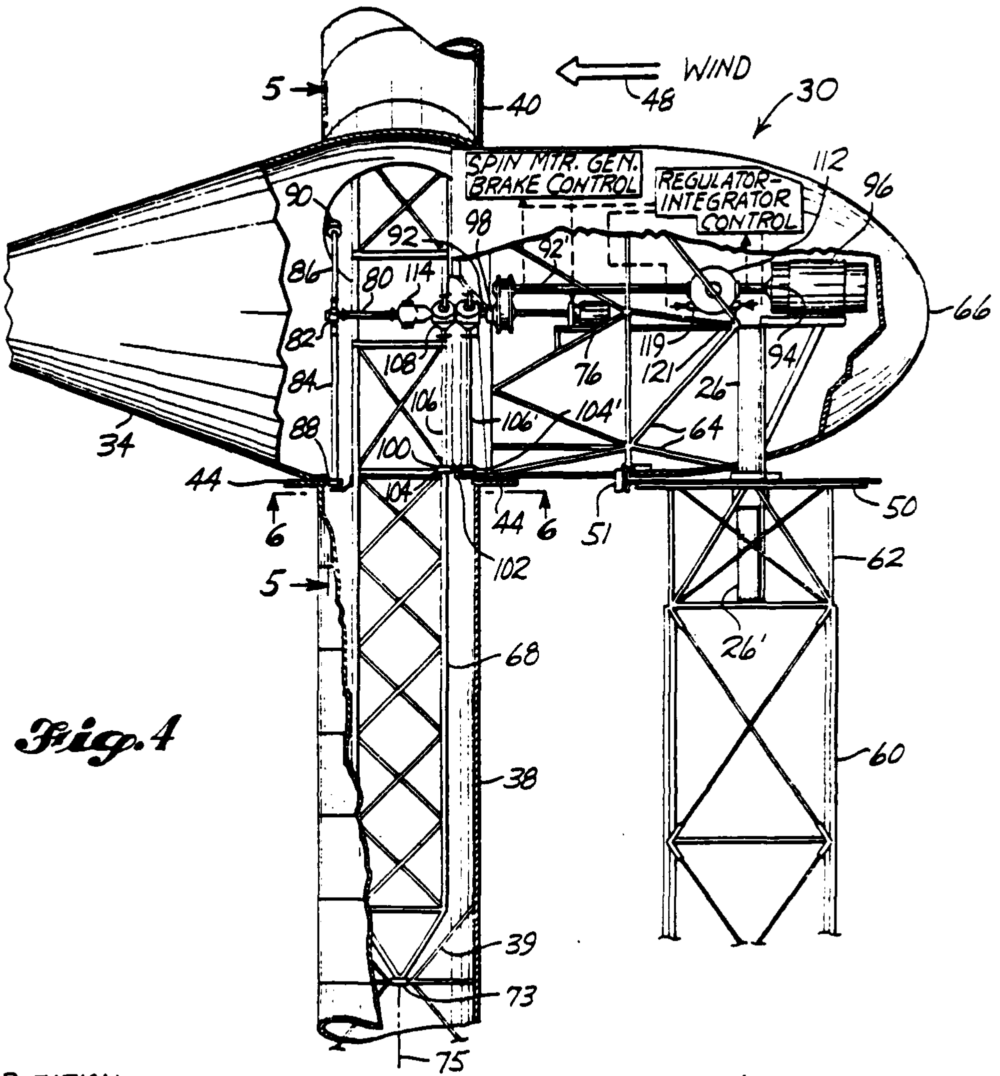


Fig.4

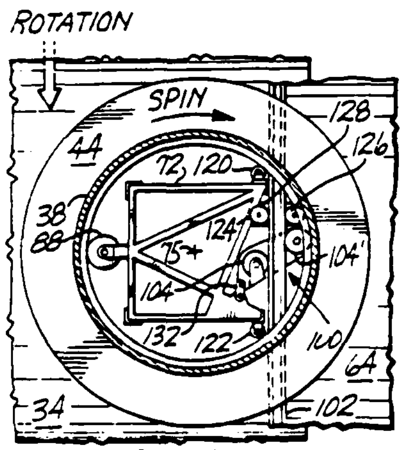


Fig.6

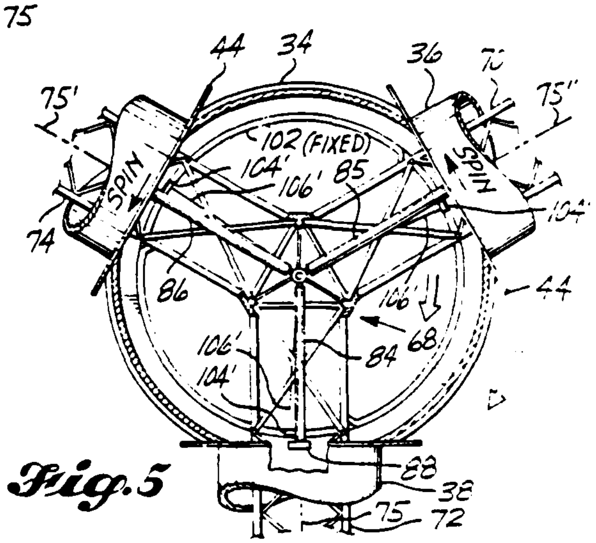


Fig.5

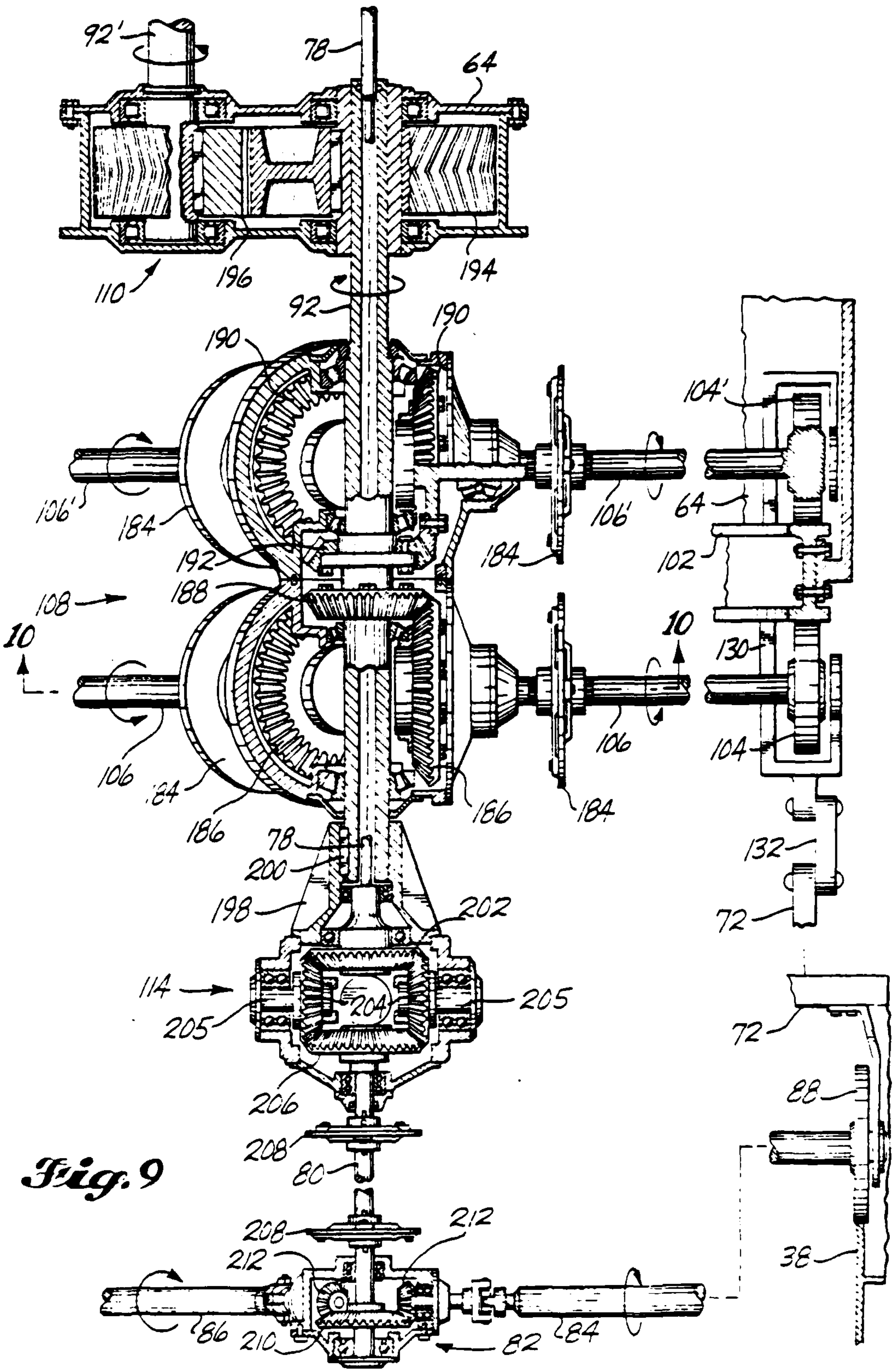

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Fig. 9

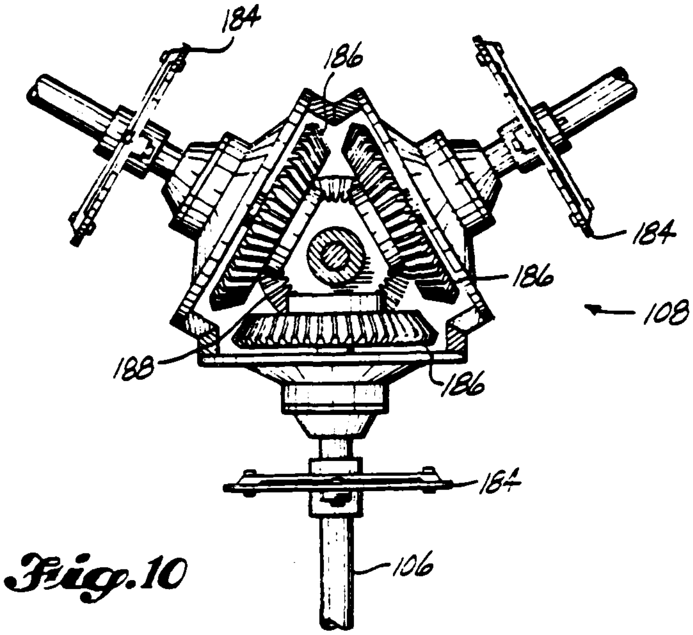


Fig. 10

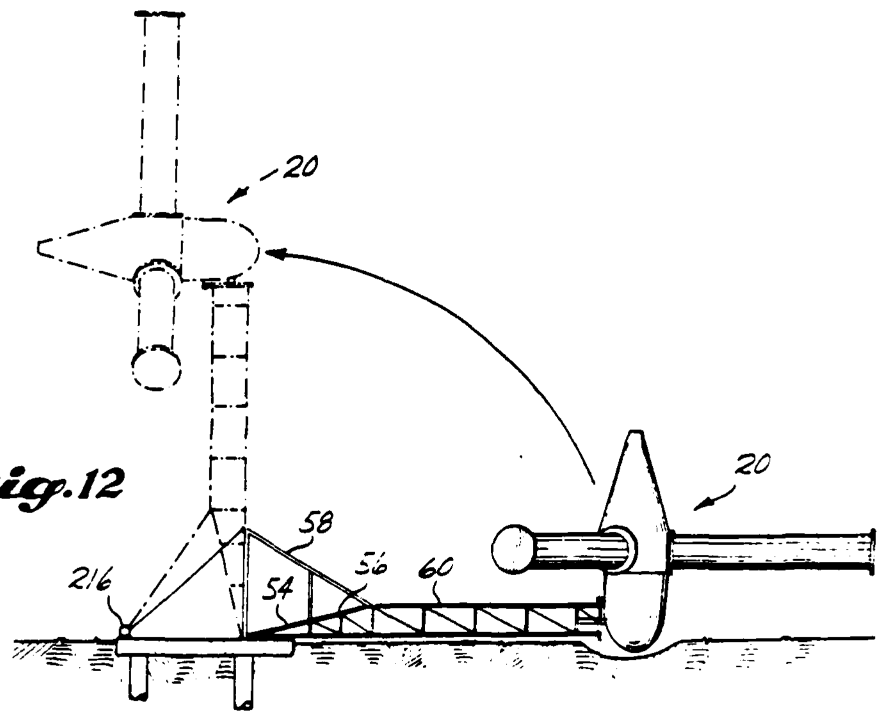


Fig. 12

J.L. BORG AND C.J. BORG, MAGNUS EFFECT POWER GENERATOR, U.S. PATENT 4,446,379 ISSUED MAY 1, 1984

The Borg vertical axis machine employs a concept similar to Sargent's wind motor (see page 63). The rotors are motor driven and turn through a 180 degree arc by means of their own lift rather using a multilated bevel gear.

- Figure 1 illustrates the wind-driven version of the system. A column (item 7) is mounted upon a flywheel (item 14). The column supports two crossarms (item 5) each of which has a rotor (item 1) and a drive motor (item 4). The rotor assemblies are oriented in opposite directions so that the downwind and the upwind rotors apply torque (rotors A and B), while the rotors in the idle quadrants (C and D) coast through in a horizontal position, causing minimum drag. As the rotors come into the wind, they briefly act like propellers and swing into working postion against stops (items 21 and 22). When the cylinders lose the Magnus effect lift, they become horizontal and counter-balance each other. Energy is taken out at the edge of the flywheel by a friction driven electric generator (item 16), a pump (item 17), or any similar device. The unit is supported upon a shaft and bearings (items 8 and 9). Power to drive the motor is furnished by an electrical control box (item 10) through slipring connectors (item 11).

- Figure 2 depicts a second embodiment of the invention in which the system is inverted and suspended in a river or tidal flow beneath a barge.

- Figures 3, 4, and 5 explain the flip-over action of the rotors.

ASSESSMENT: This invention is a high-torque, low-velocity machine that is omnidirectional with respect to the wind or current. The gyro effect of the flywheel contributes to its stability in high winds.

United States Patent [19]

Borg et al.

[11] **4,446,379**

[45] **May 1, 1984**

[54] **MAGNUS EFFECT POWER GENERATOR**

[76] Inventors: **John L. Borg; Catherine J. Borg**, both of 8200 Toro Creek Rd., Atascadero, Calif. 93422

[21] Appl. No.: **467,220**

[22] Filed: **Feb. 17, 1983**

[51] **Int. Cl.**[3] **F01D 1/36; F03B 5/00; F03D 9/02**

[52] **U.S. Cl.** **290/55;** 416/4; 416/117

[58] **Field of Search** .... 416/4, 117 R; 290/44, 290/55

[56] **References Cited**

U.S. PATENT DOCUMENTS

1,744,924 1/1930 **Sargent** 416/4

Primary Examiner—B. Dobeck

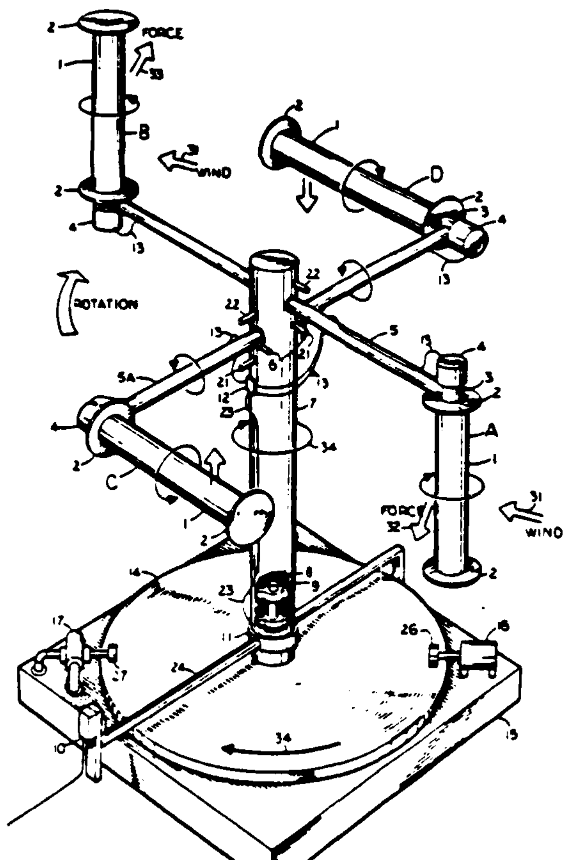
Assistant Examiner—Shelley Wade

Attorney, Agent, or Firm—Harry W. Breisford

[57] **ABSTRACT**

Magnus cylinders are mounted for rotation at right angles to shafts that are revolved about a generally vertical axis. The shafts are free to rotate 180°. The Magnus cylinders are continuously rotated in the same angular direction. At one position of revolution of the shafts, the cylinders rotate on an axis generally parallel to the axis of revolution of the shafts. When the apparatus is immersed in a fluid flow (gaseous or liquid) a torque of rotation is developed when the shafts are aligned with the fluid flow, and this torque of rotation is reduced as the shaft approaches a position transverse to the fluid flow. As the shafts pass this transverse position, a torque is developed by the rotating cylinder that rotates the shafts 180° until the formerly downwardly depending cylinder is now upright and the formerly upright cylinder is now downwardly depending on its shaft. With two or more shafts to which cylinders are attached, there is a continuous production of torque about the axis of revolution of the shafts.

7 Claims, 5 Drawing Figures



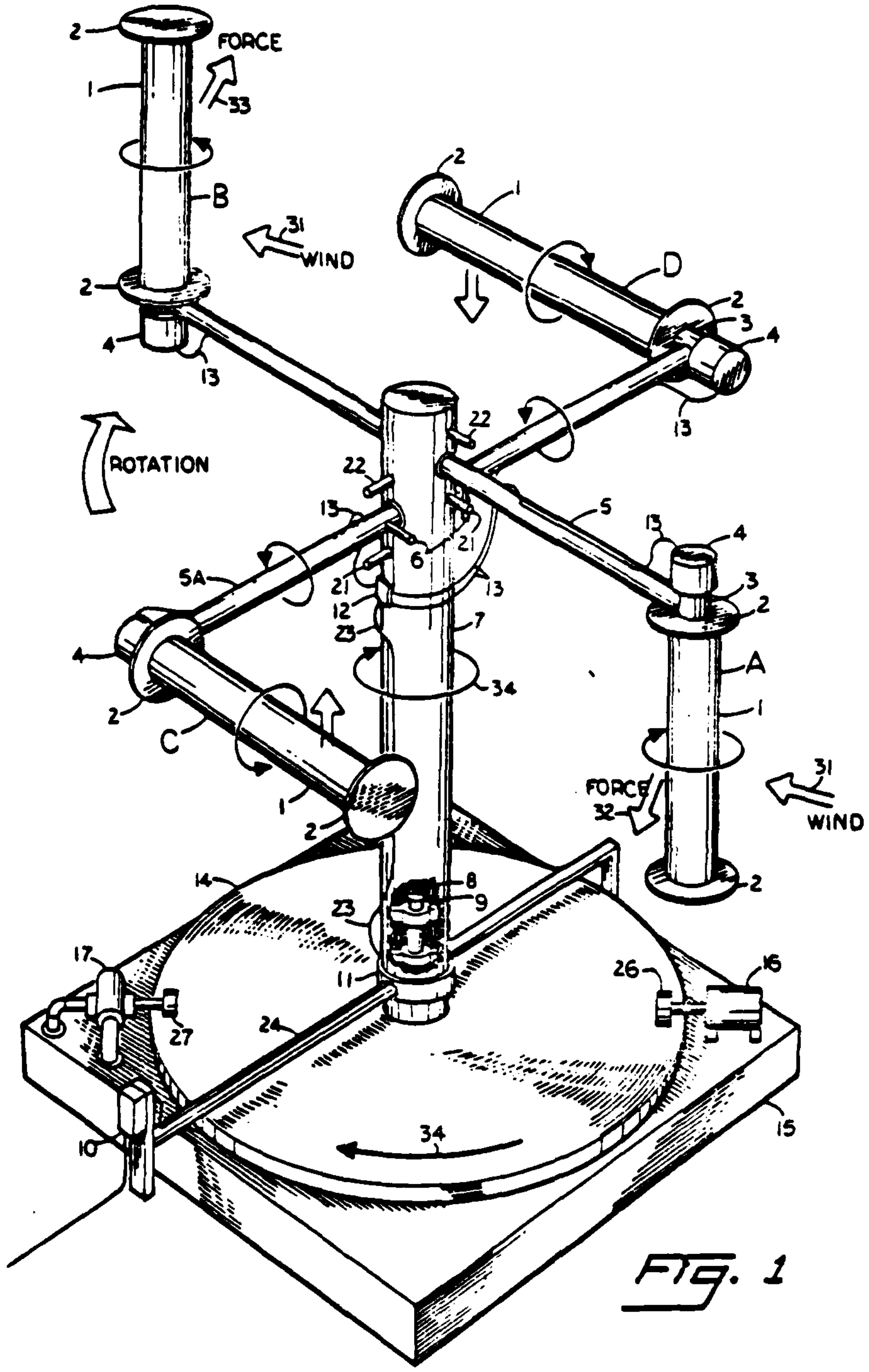

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FIG. 1

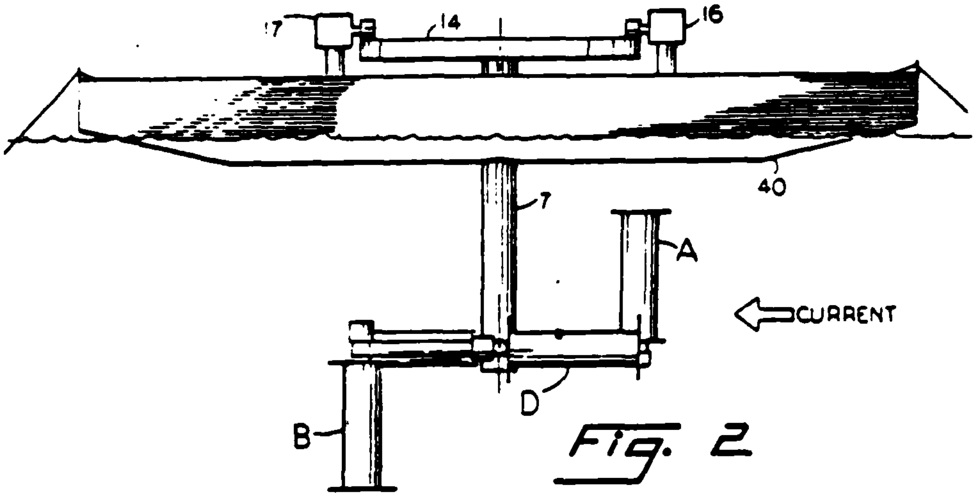


Fig. 2

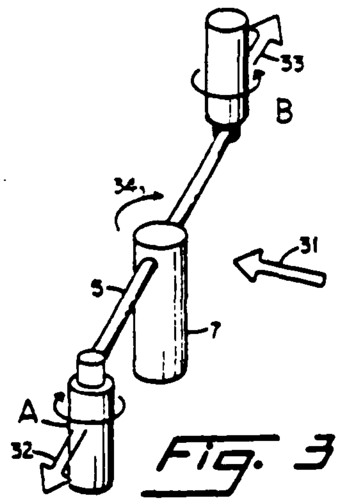


Fig. 3

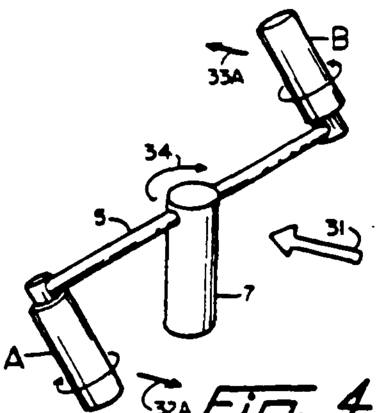


Fig. 4

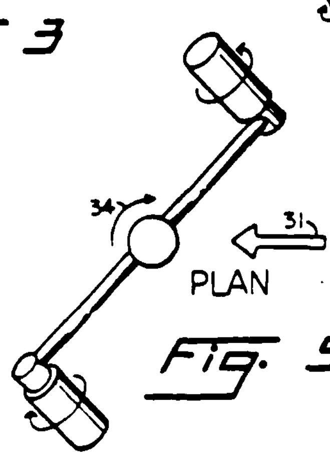


Fig. 5

AIRCRAFT

O.L. DALLY, AERIAL VESSEL, U.S. PATENT 1,665,533, ISSUED APRIL 10, 1928

The Dally Aerial Vessel is an attempt to replace the wings of a monoplane with air turbine-driven rotors.

- Figure 1 is a top plan view of the aircraft.
- Figure 2 is a front elevation.
- Figure 3 is a longitudinal section through one of the rotor wings.
- Figure 4 is a fragmentary view of the inboard end of the rotor which shows the air turbine drive arrangement.
- Figure 5 is a similar section showing a sort of funnel whose function is to focus high velocity air at the impeller blades.
- Figure 6 is a sectional plan view of the rotor mounting arrangement.
- Figure 7 is a section on line 7-7 of Figure 3.
- Figure 8 is a section on line 8-8 of Figure 5.
- Figure 9 is a perspective of the shield for the turbine.
- Figures 10 and 11 are diagrammatical views illustrating the forces acting upon the rotors.

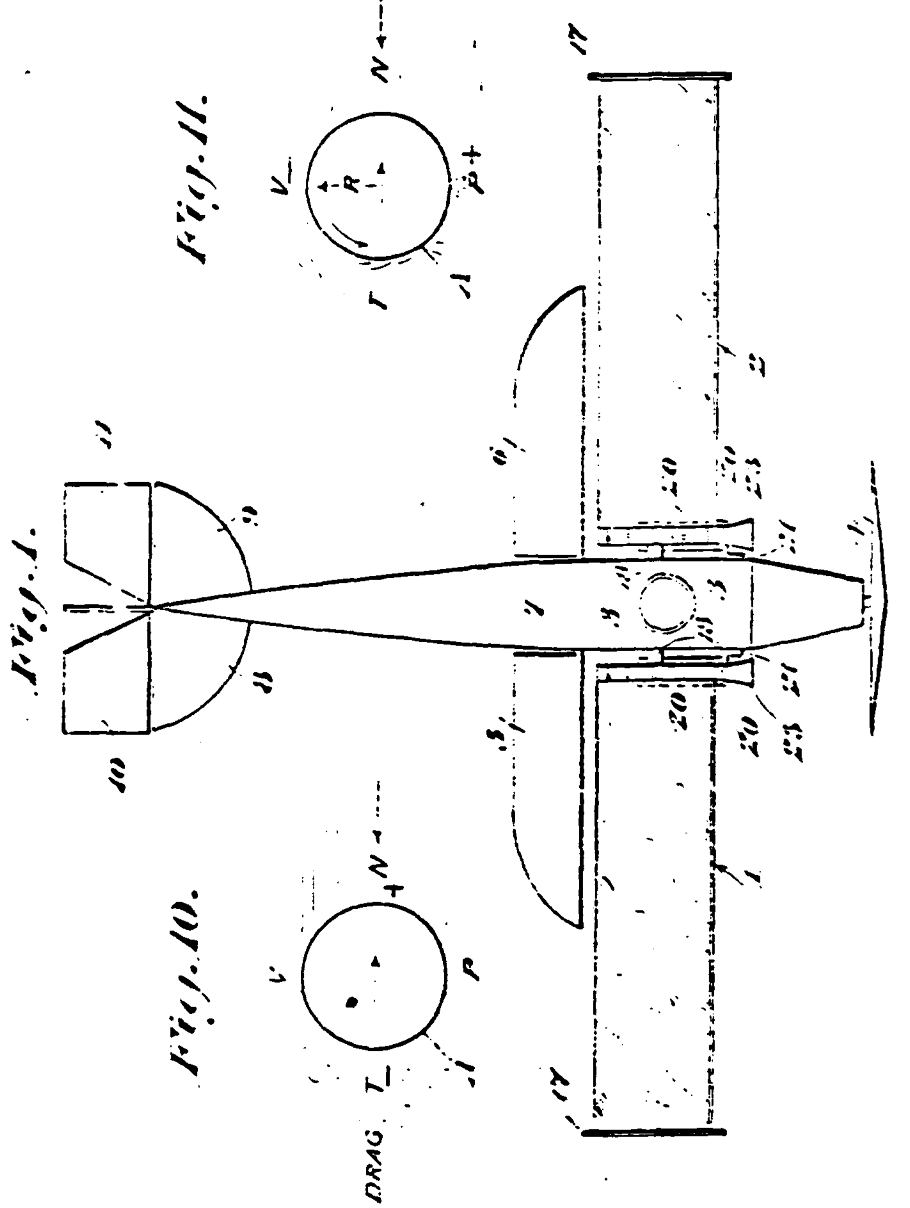
ASSESSMENT: An obvious problem inherent in Dally's invention is that the faster it flies the more lift it will develop and hence would have difficulty maintaining a constant altitude. Some sort of butterfly valve or damper located in the impeller funnels would be helpful in controlling excessive lift. As shown, this aircraft would probably take off in a short distance, have an impressive rate of climb but unsatisfactory performance once in the air.

April 10, 1928. 1,665,533

O. L. DALLY

AERIAL VESSEL

Filed Oct. 22, 1925 3 Sheets-Sheet 1



INVENTOR.

Orid L. Dally.

BY

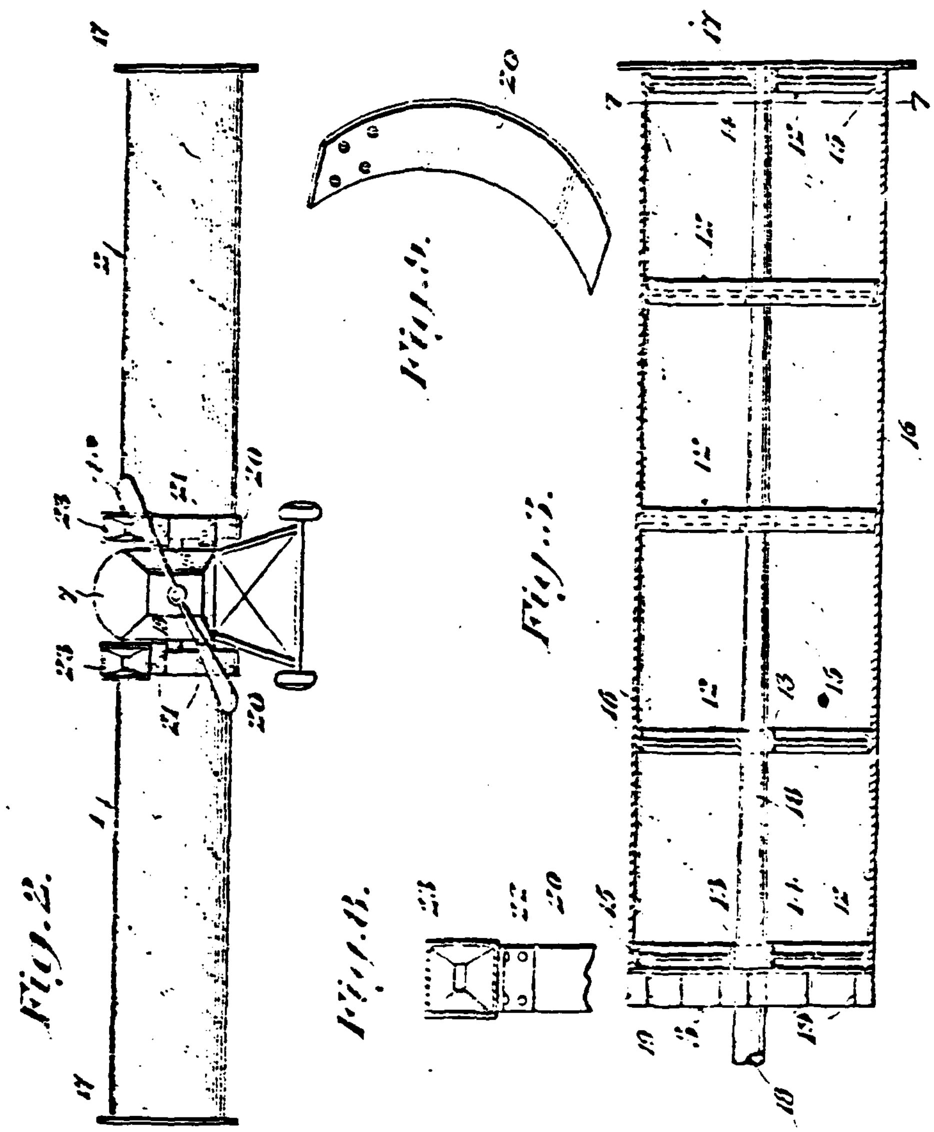
Geo. P. Kimmel ATTORNEY.

April 10, 1928. 1,665,533

O. L. DALLY

AERIAL VESSEL

Filed Oct. 22, 1925 3 Sheets-Sheet 2



INVENTOR.

Ovid L. Dally.

BY

Geo. P. Kimmel

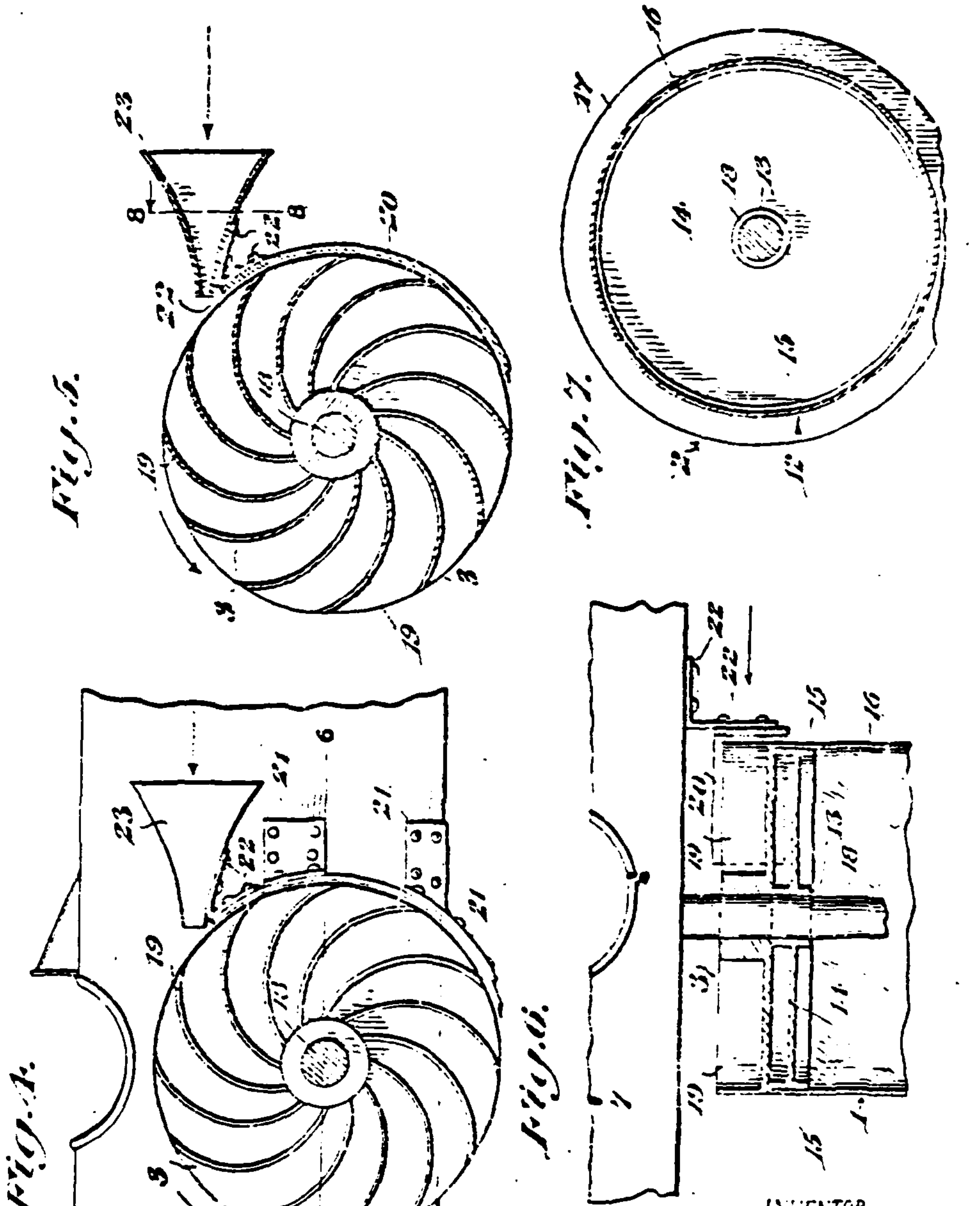
ATTORNEY.

April 10, 1928. 1,665,533

O. L. DALLY

AERIAL VESSEL

Filed Oct. 22, 1925 3 Sheets-Sheet 3



INVENTOR.

Ovid L. Dally,

BY

Geo. P. Kimmel

ATTORNEY.

F. De La TOUR CASTELCICALA, ROLLING APRON FOR AIRPLANE WINGS, U.S. PATENT 1,785,300, ISSUED DECEMBER 16, 1930

This invention shows how a wing can produce Magnus effect lift by means of a moving surface composed of sprocket driven endless belt elements passing over rollers.

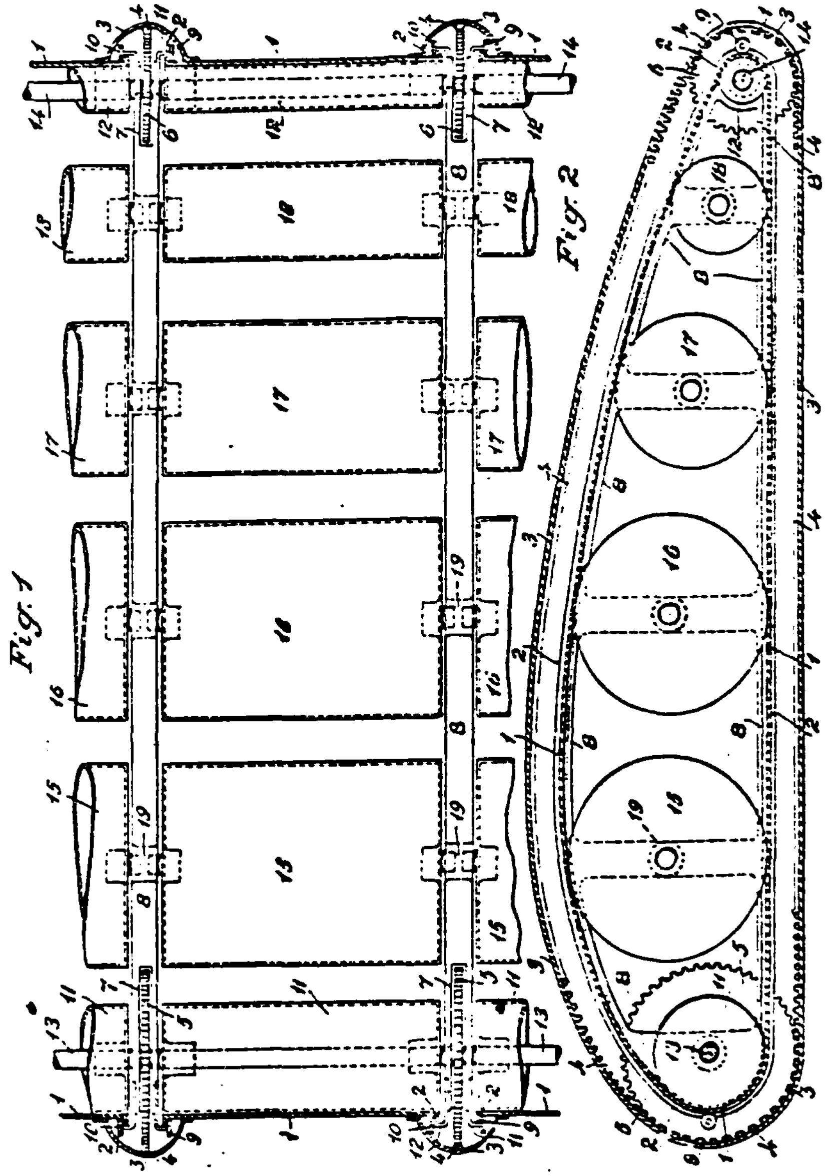
- Figure 1 is a partial plan view of such a wing.
- Figure 2 is a cross-section showing rollers having various diameters arranged in an airfoil-like contour.

ASSESSMENT: There is nothing wrong with the moving-belt, airfoil-surface concept. The benefit of increased Magnus effect lift, however, would probably be cancelled by the excessive weight of the configuration shown in this patent. In other words, the endless belt idea, while theoretically correct, would none-the-less be impractical if driven mechanically.

Dec. 16, 1930. F. DE LA TOUR CASTELCICALA 1,785,300

ROLLING APRON FOR AIRPLANE WINGS

Filed Aug. 2, 1929



Filiberto de la tour Castelcicala
INVENTOR:
By [signature]
his Attorney.

F.A. HOWARD, AIRCRAFT, U.S. PATENT 1,796,789, ISSUED MARCH 17, 1931, ASSIGNED TO STANDARD OIL DEVELOPMENT COMPANY

The Howard Aircraft is a helicopter having counterrotating Magnus effect rotor propellers.

- Figure 1 and 2 respectively are, a side elevation and frontal view of the machine showing its tapered rotors and side mounted radial engines.

- Figure 3 is a sectional view showing the rotor drive arrangement.

- Figure 4 is a side elevation showing an alternative drive arrangement with vertical axis radial engines and Figure 5 is a cut-away frontal view of the same.

- Figure 6 shows two sectional views of the rotor friction drive system.

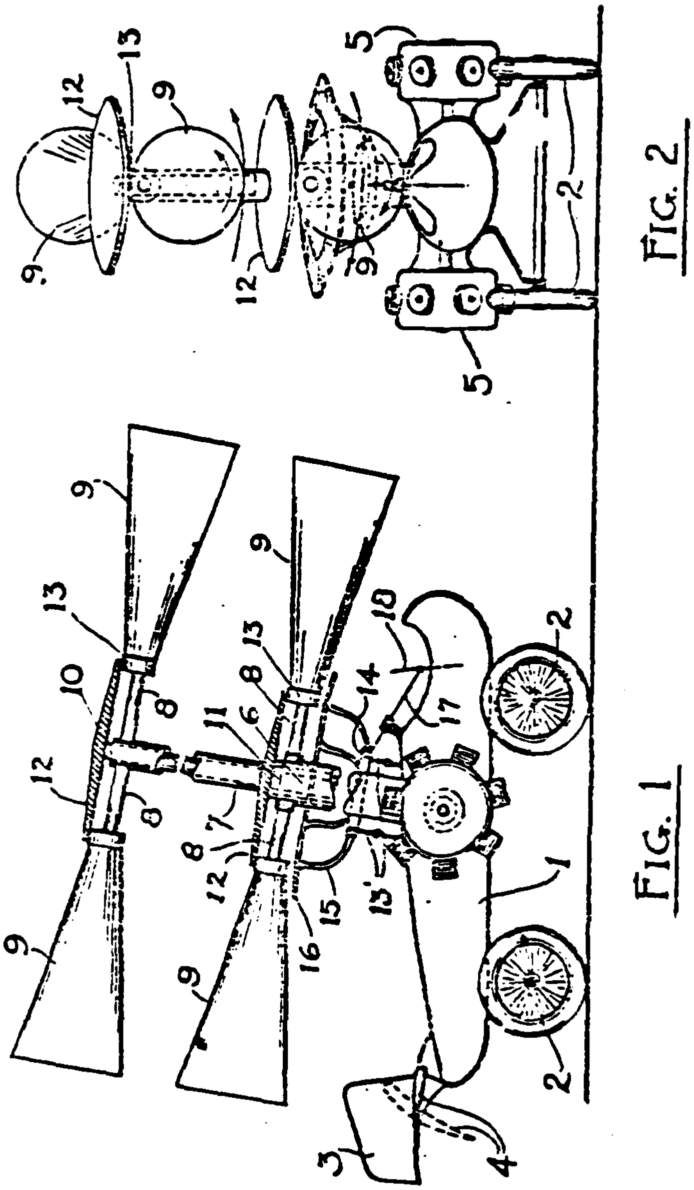
- Figure 7, the driving arrangements have been modified in that the lower friction table (item 73) is mounted directly on the sleeve (item 7), thus eliminating the intermediate sleeve (item 11) illustrated in Figure 1.

ASSESSMENT: The idea of tapered rotors may have some merit, but the positioning of one set of rotors directly above the other would cause heavy vibration problems.

March 17, 1931. F. A. HOWARD 1,796,789

AIRCRAFT

Filed June 11, 1928 5 Sheets-Sheet 1



Frank A. Howard Inventor

By C. A. Straw Attorney

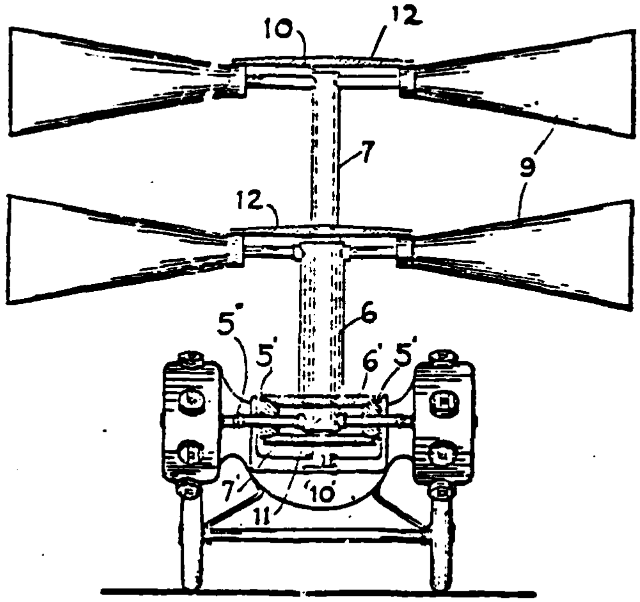


FIG.-3

FRANK A. HOWARD Inventor
By Attorney

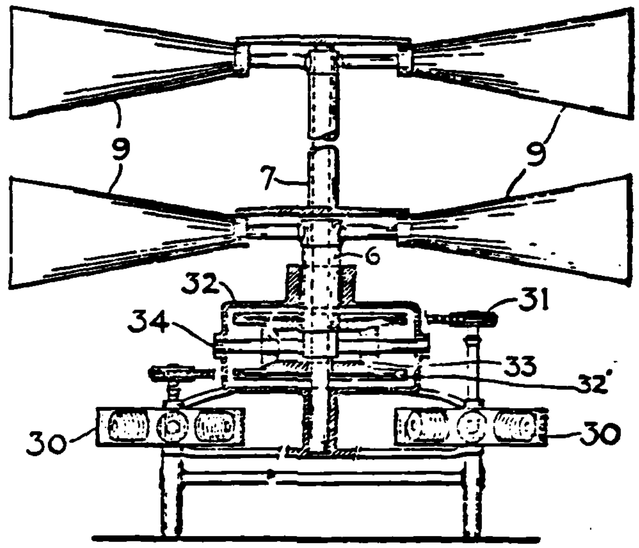


FIG.-5

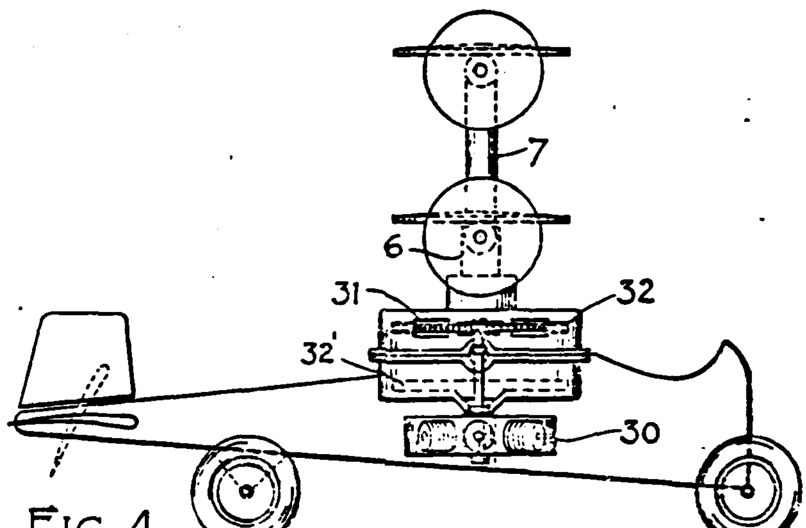


FIG.-4

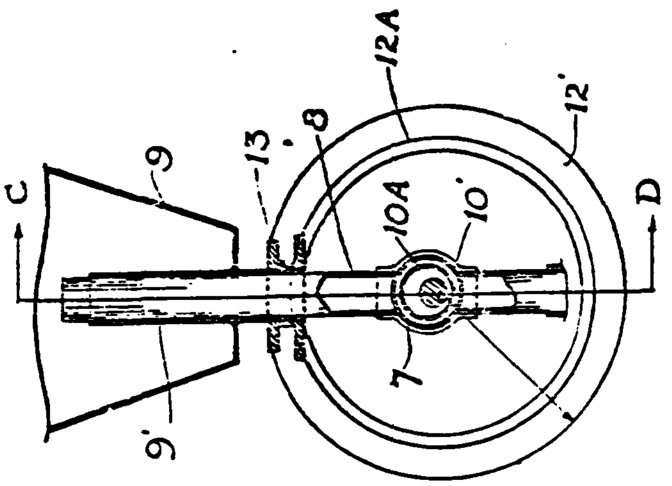
Frank A. Howard Inventor

By Attorney

March 17, 1931. F. A. HOWARD 1,796,789

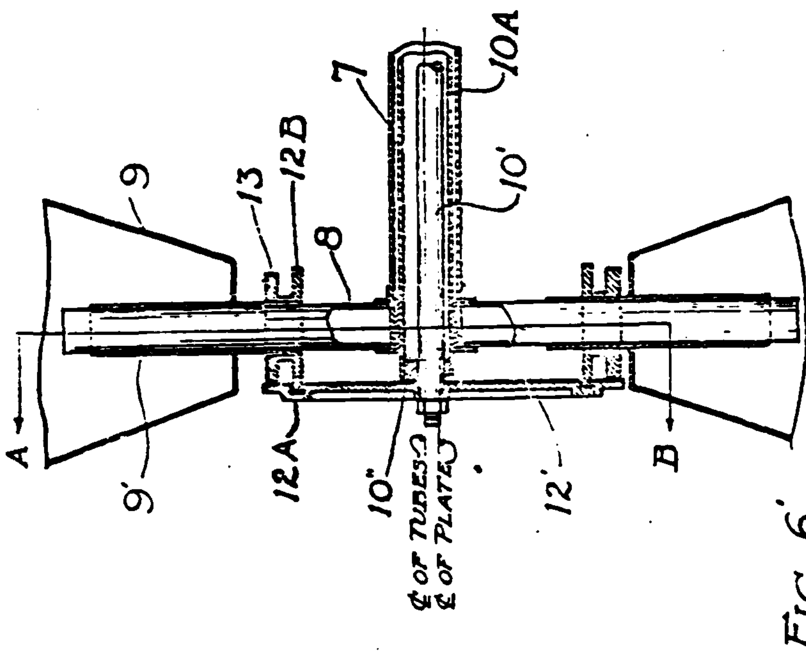
AIRCRAFT

Filed June 11, 1925 5 Sheets-Sheet 4



SECTION A.B

FIG-6



SECTION C.D.

FIG. 6'

Frank A. Howard Inventor

By [signature] Attorney

March 17, 1931. F. A. HOWARD 1,796,789

AIRCRAFT

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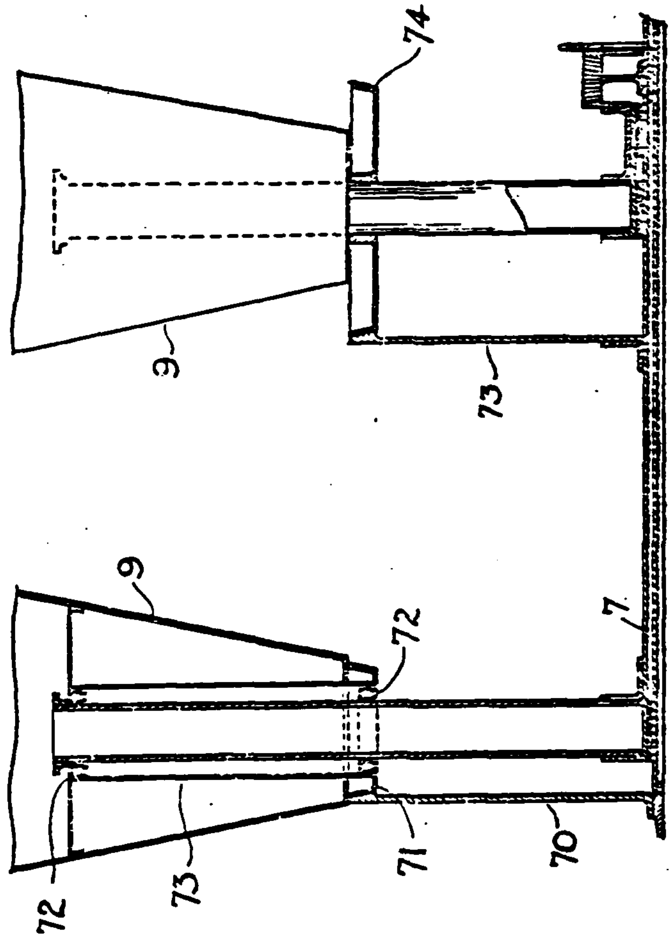


FIG.-7

Frank A. Howard Inventor

By [signature] Attorney

R. TARSHIS, HELICOPTER, U.S. PATENT 1,807,353, ISSUED MAY 26, 1931

It is astonishing that Mr. Tarshis was awarded a patent for his helicopter.

- Figures 1 and 2 are front and side elevations of the basic device fitted with three gear driven rotors and a vertical axis propeller. The text states that item 55 is a gasoline engine whose exhaust is ducted to nozzles used for steering.
- Figures 4 and 5 show a modification that has nine little propellers to provide air flow across the cylinders.

The inventor makes no mention of flight stability in his claims.

ASSESSMENT: The multitude of rotors and propellers would certainly get in each others way and render the device flightless.

May 26, 1931. R. TARSHIS 1,807,353

HELICOPTER

Original Filed Oct. 10, 1928

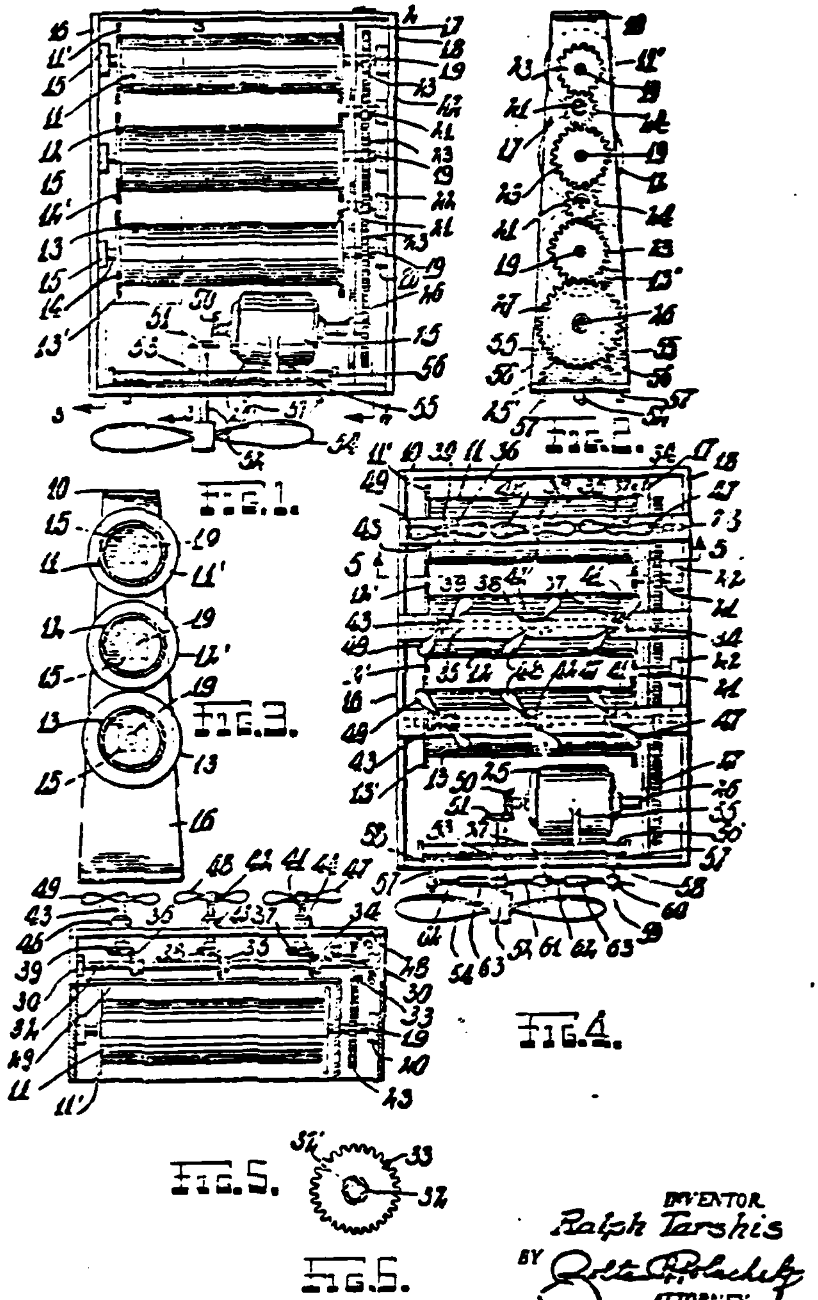


FIG. 1. FIG. 2. FIG. 3. FIG. 4. FIG. 5. FIG. 6.

INVENTOR
Ralph Tarshis
BY [illegible]
ATTORNEY

H.P. MASSEY, AIRCRAFT, U.S. PATENT 1,820,919, ISSUED SEPTEMBER 1, 1931

This aircraft combines Magnus effect lifting surfaces and jet propulsion. The inventor claims to a lifting effect both with and without a forward movement of the airplane relative to the earth.

- Figure 1 shows the airplane in plan view.
- Figure 2 shows a side elevation with the rotors and associated cylinder member section.

An engine in the forward part of the fuselage drives the rotors through bevel gears as well as an internal propeller to provide forward thrust through a duct. The rotor forms the leading edge of a complex slotted wing. The outer slotted rotors spin counterclockwise. Within it is a fixed cylindrical shroud having a single longitudinal slot that is adjustable for direction. Within the cylinder is a second rotor turning in a clockwise direction whose purpose is to draw air into the body of the aircraft.

ASSESSMENT: *It is very doubtful that this one would get off the ground.*

Sept. 1, 1931. H. P. MASSEY 1,820,919

AIRCRAFT

Filed May 31, 1930 2 Sheets-Sheet 1

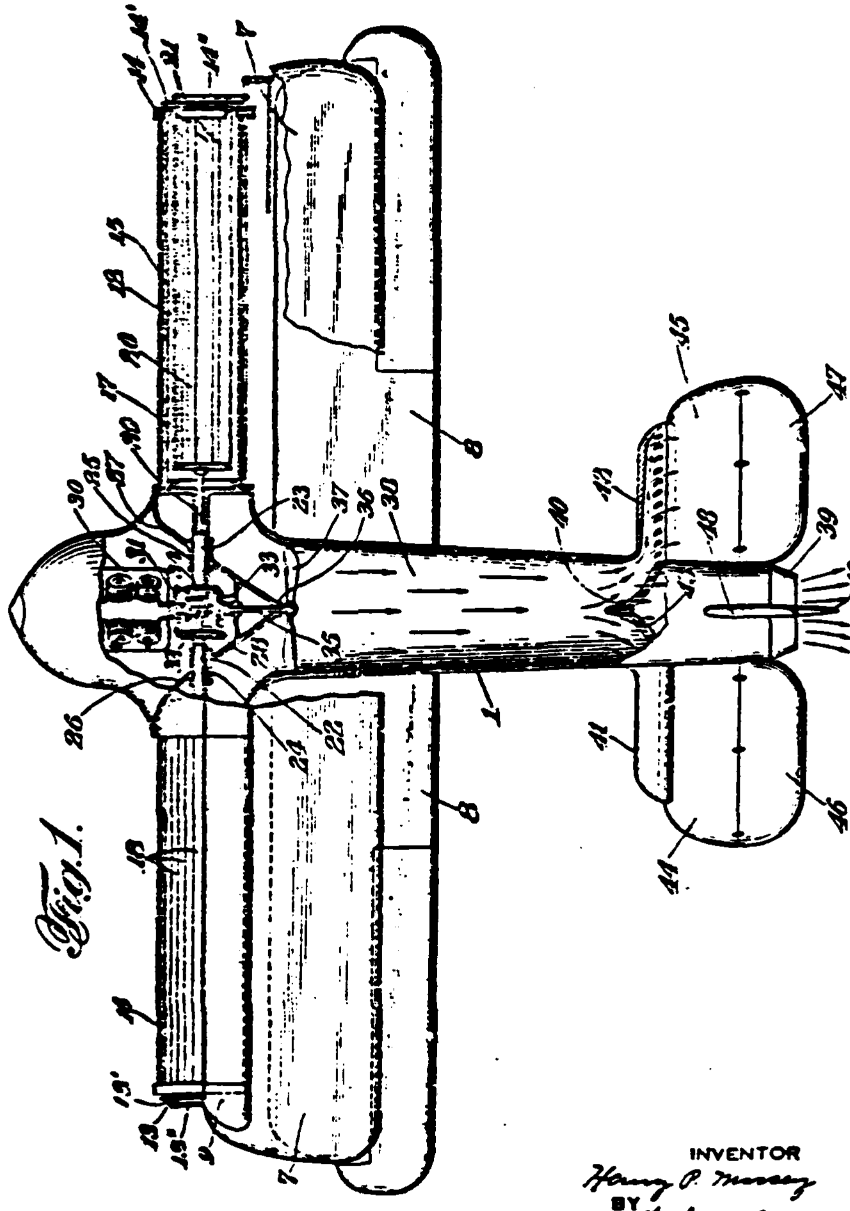


Fig. 1.

INVENTOR

Harry P. Massey

BY Hand Cooley & Neal

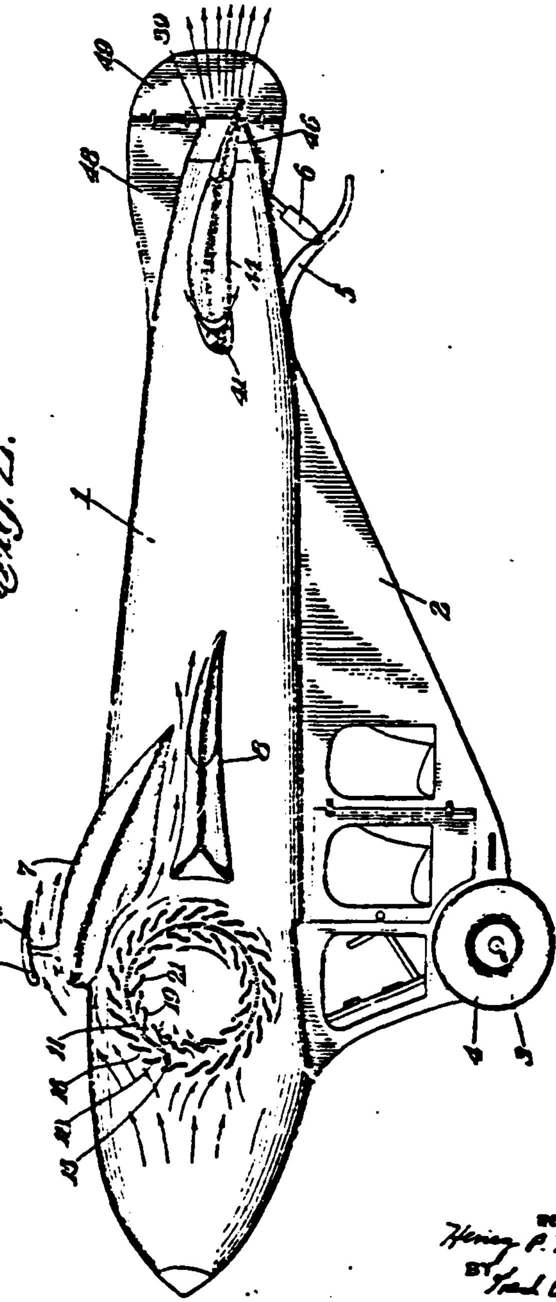
his ATTORNEYS

Sept. 1, 1931. H. P. MASSEY 1,820,919

AIRCRAFT

Filed May 31, 1930 2 Sheets-Sheet 2

Fig. 2.



INVENTOR
Henry P. Massey
BY Ward, Crosby & Neal
ATTORNEYS

F. WANDER, JR., AUTOHELIROTOR, U.S. PATENT 1,834,558, ISSUED DECEMBER 1, 1931

The main claim of this patent relates to using segmented rotor blades for helicopters, in order that the peripheral velocity at the tip will be greater than at the hub. There is no reason to do this because it causes a loss of lift near the hub where it is most needed. Autorotors appear for the first time in this patent. Two types are shown, an "S" shape and a Savonius.

- Figure 1 is a fragmentary side elevation of an airship fitted with autorotors and Figure 2 is a plan view.
- Figure 3 is a view of one of the segmented rotors.
- Figure 4 is a section through a Savonius type rotor.
- Figure 5 is a sectional view taken along line 5-5 of Figure 4, showing bearings and internal struts.
- Figure 6 is a section through the "S" type autorotor.
- Figures 7, 8 and 9 show a means for revolving the rotor segments at various speeds using right angle gears.
- Figure 10 shows the mountings of the blade sections upon the telescoping tubular members.
- Figure 11 shows a rotor having angular plates in each segment, but no explanation is given for this.
- Figure 12 is a ship with four autorotors mounted on the deck but the text does not clarify this either.

ASSESSMENT: Although autorotors have proven to be fairly good windmill baldes, their value as lifting devices is probably not great.

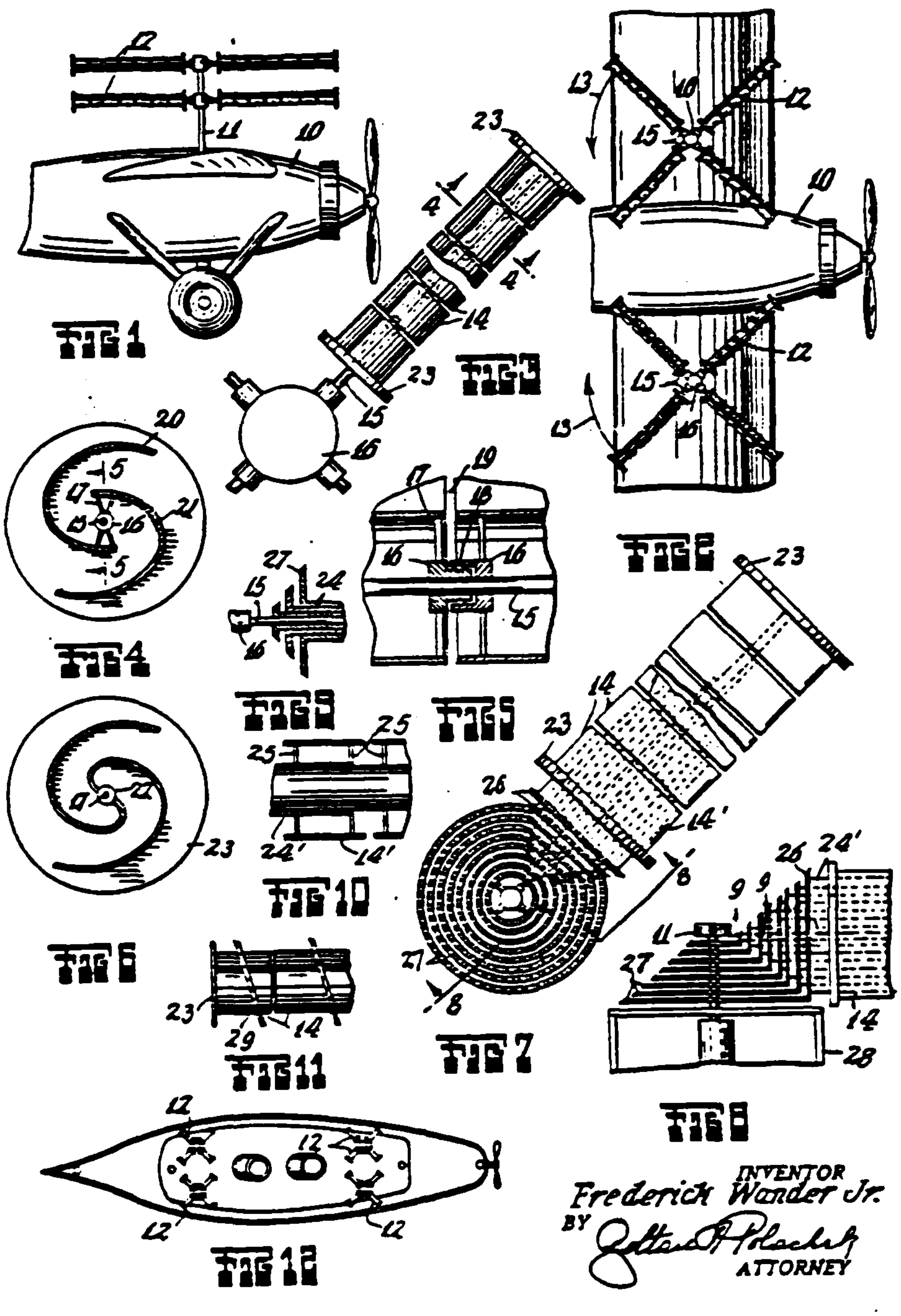
416-4

Examiner

Dec. 1, 1931. F. WANDER, JR 1,834,558

AUTOHELIROTOR

Filed May 11, 1931



E.F. ZAPARKA SUSTAINING AND CONTROL SURFACE, U.S. PATENT 1,927,538, ISSUED SEPTEMBER 19, 1933

The Zaparka patent covers a large assortment of Magnus effect applications and drive systems for aircraft and ships.

- Figures 1 through 6 are airflow diagrams.
- Figures 7 and 8 show a wind-driven, lift-enhancing arrangement for winged aircraft.
- Figures 9 and 10 are turbine rotor drives.
- Figures 11 and 12 are an aircraft with a combination wind driven and powered rotor wing.
- Figures 13 and 14 are a sort of Magnus effect airship with internal lifting rotors.
- Figure 15 is an aircraft with a rotor wing driven by an internal Archimedes' screw.
- Figures 16 and 17 show a rotor steering system with the same type of drive.
- Figures 18 and 19 relate to a multiple rotor wing arrangement having controllable airfoils positioned behind them.
- Figures 20,21 and 22 show an auxiliary rotor wing that retracts within a conventional wing and a system for maintaining trim by stabilizer adjustment is included.
- Figures 23 and 24 are similar systems for a flying boat.
- Figures 25 and 26 show an unusual lifting machine with six rotors and opposing propellers.
- Figures 27 and 28 illustrate a lift boosting system for a dirigible.
- Figures 29 is a helicopter.
- Figures 30 and 31 look like a ship's stabilizer system but the text states that it is a means for decreasing the vessel's displacement.

- Figures 32, 33 and 34 show Magnus effect control surfaces for submarines.

- Figure 35 is a cross-sectional detail of a water impelled rotor for marine applications.

ASSESSMENT: Mr. Zaparka tried to cover everything in one patent but nothing evolved. He did come very close to inventing a Magnus effect ship stabilizer.

Sept. 19, 1933. E. F. ZAPARKA 1,927,538

SUSTAINING AND CONTROL SURFACE

Filed March 1, 1930 10 Sheets-Sheet 1

Fig. 1.

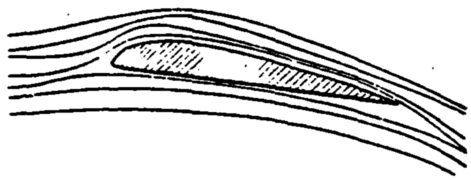


Fig. 2.

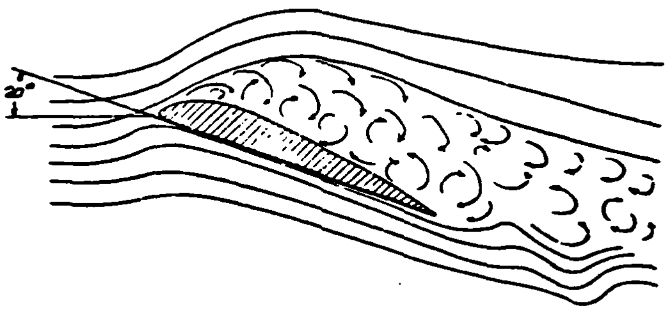
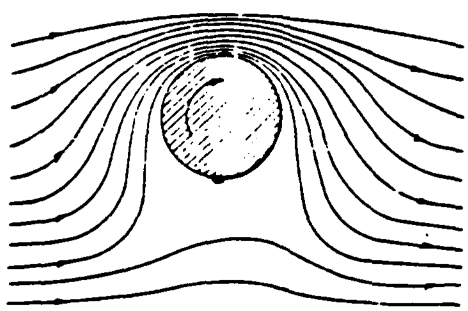


Fig. 3.



INVENTOR.

Edward F. Zaparka

BY Dodd, Dunn & Anderson

ATTORNEYS.

Fig. 4.

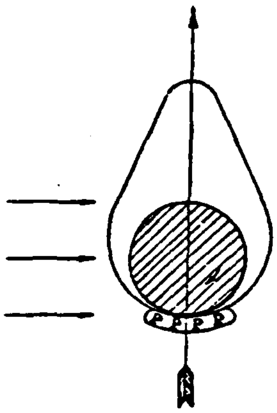


Fig. 5.

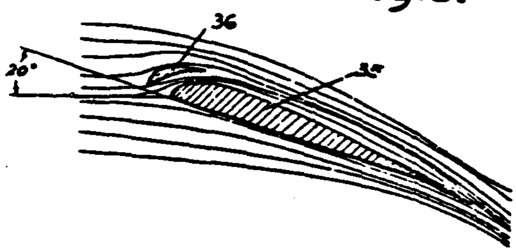
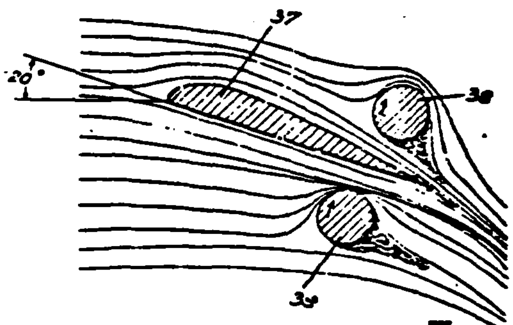


Fig. 6.



INVENTOR
Edward F. Zaparka
BY
ATTORNEYS

Sept. 19, 1933. E. F. ZAPARKA 1,927,538

SUSTAINING AND CONTROL SURFACE

Filed March 1, 1930 10 Sheets-Sheet 3

Fig. 7.

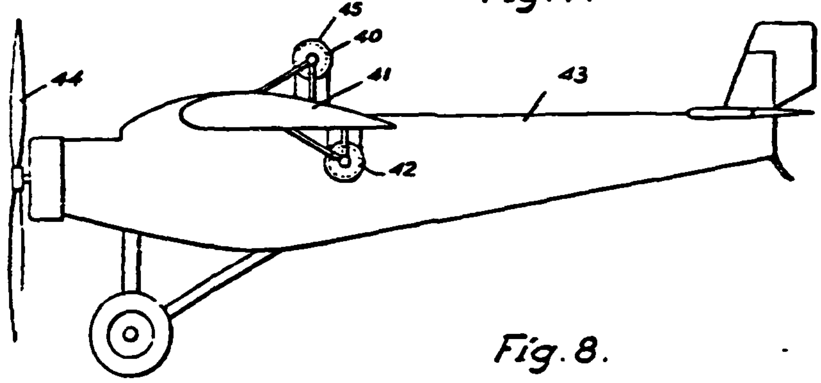


Fig. 8.

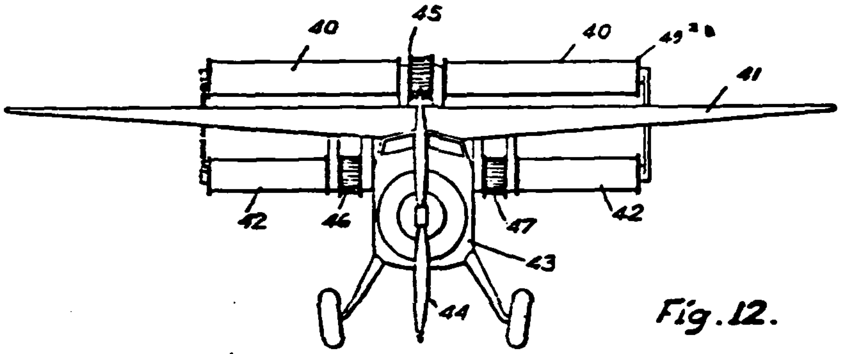
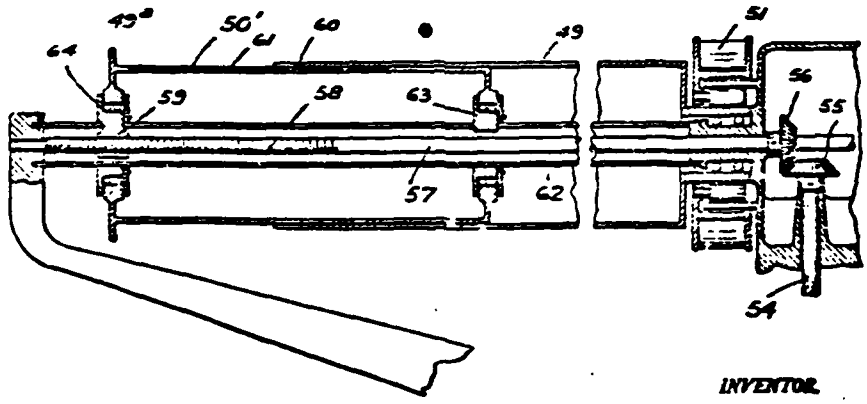


Fig. 12.



INVENTOR

Edward F. Zaparka

BY Duell, Dunn & Anderson

ATTORNEYS

Sept. 19, 1933. E. F. ZAPARKA 1,927,538

SUSTAINING AND CONTROL SURFACE

Filed March 1, 1930 10 Sheets-Sheet 4

Fig. 9.

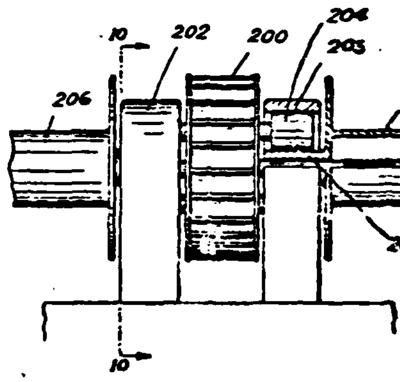


Fig. 10.

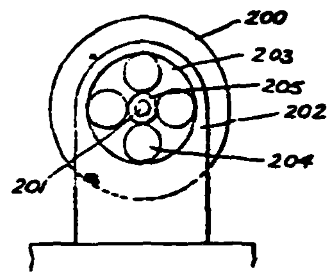
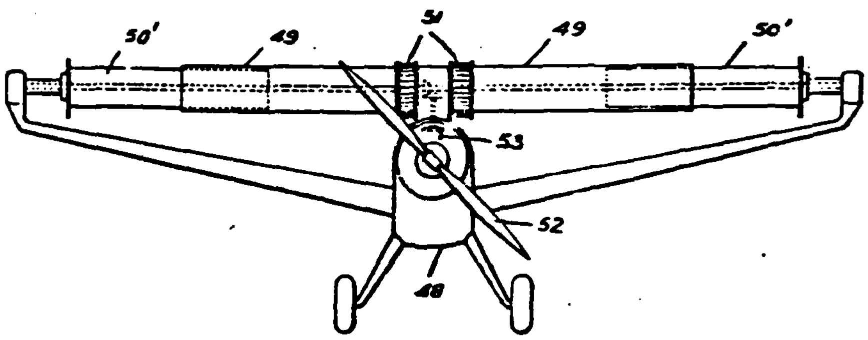


Fig. 11.



INVENTOR
Edward F. Zaparka
BY
ATTORNEYS

SUSTAINING AND CONTROL SURFACE

Filed March 1, 1930 10 Sheets-Sheet 5

Fig. 23.

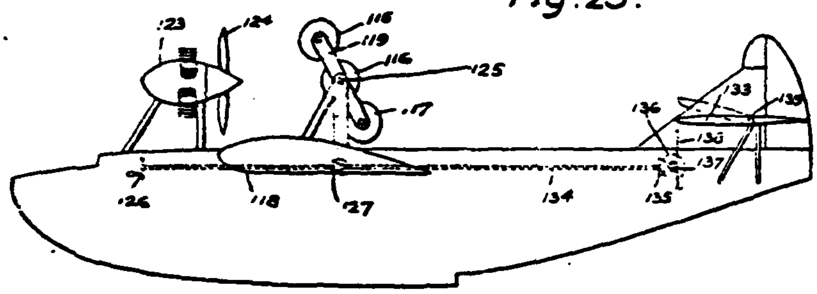


Fig. 24.

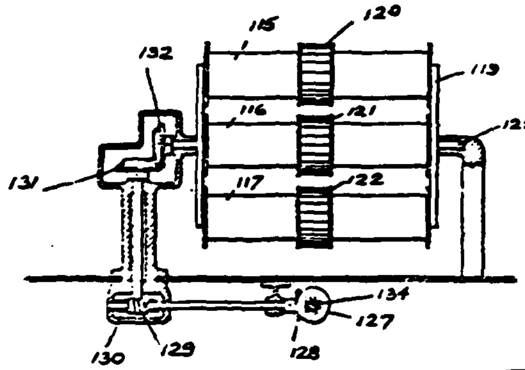


Fig. 13.

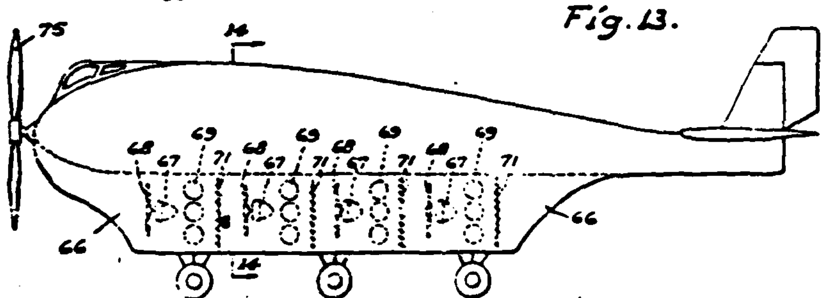
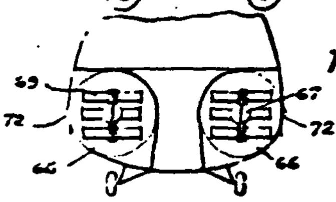


Fig. 14.



INVENTOR.

BY

ATTORNEYS.

Sept. 19, 1933. E. F. ZAPARKA 1,927,538

SUSTAINING AND CONTROL SURFACE

Filed March 1, 1930 10 Sheets-Sheet 6

Fig. 15.

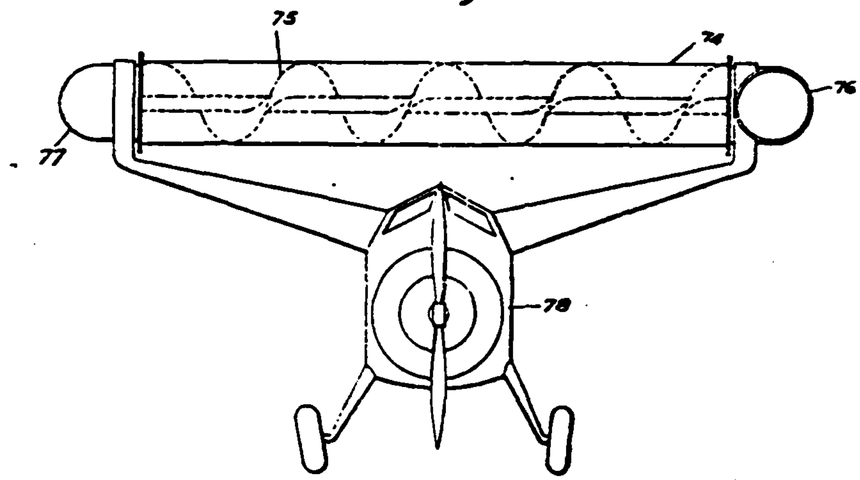
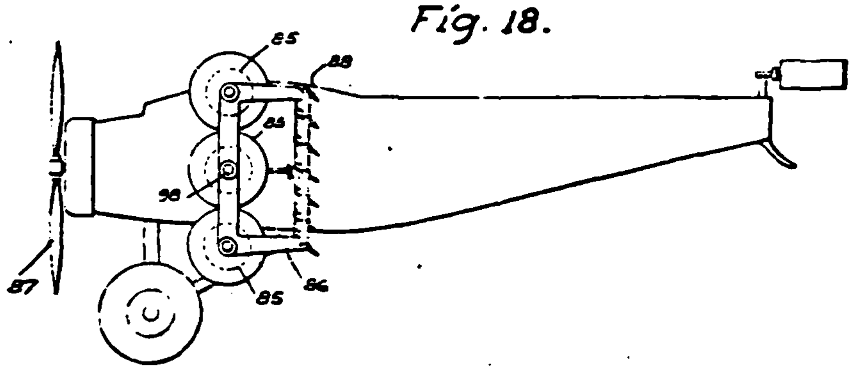


Fig. 18.



INVENTOR

Edward F. Zaparka

BY Dodd, Jones & Andrews

ATTORNEYS

Fig. 16.

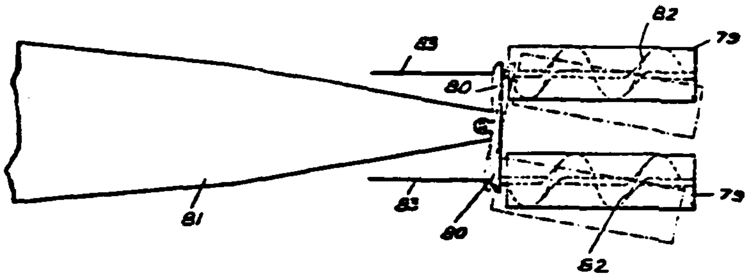


Fig. 17.

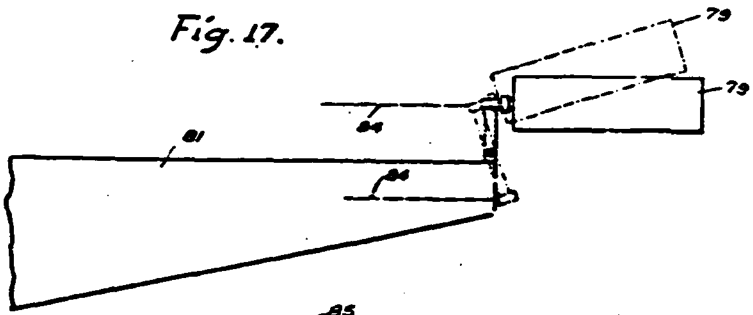
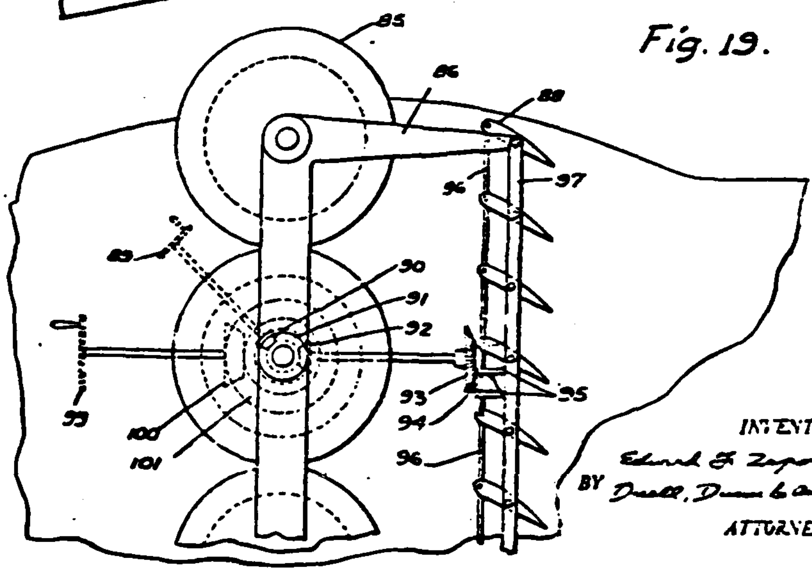


Fig. 19.



INVENTOR.

Edward F. Zaparka

BY Duell, Dunn & Anderson

ATTORNEYS.

SUSTAINING AND CONTROL SURFACE

Filed March 1, 1930 10 Sheets-Sheet 8

Fig. 20.

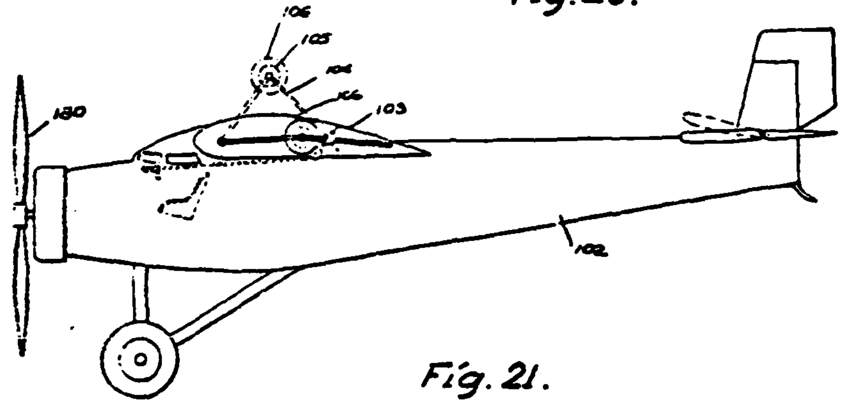


Fig. 21.

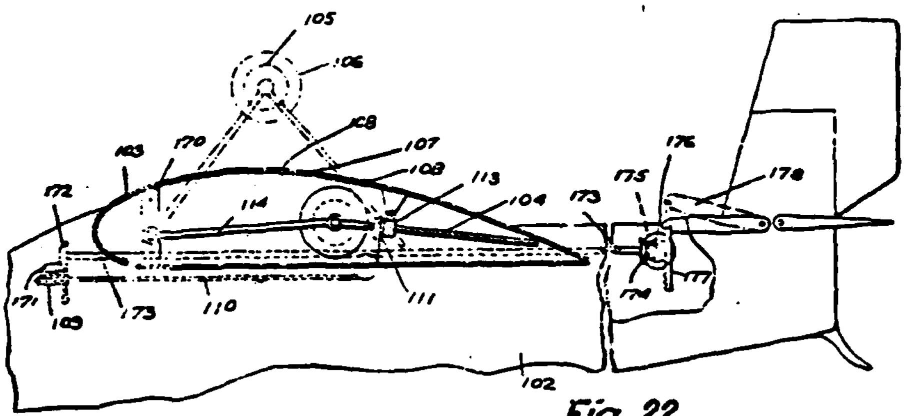
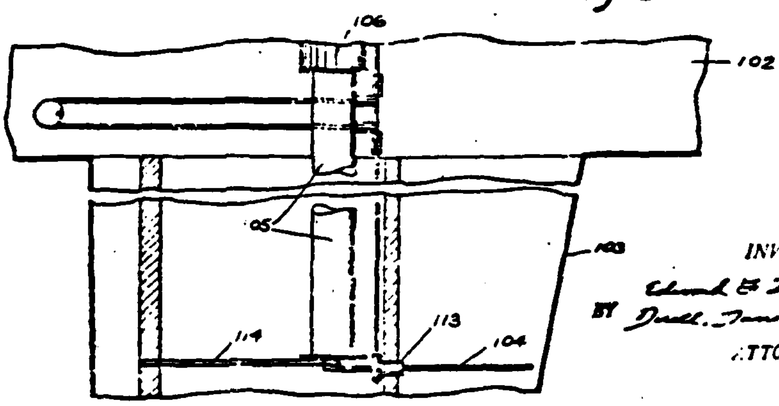


Fig. 22.



INVENTOR

Edward F. Zaparka

BY [illegible]

ATTORNEYS.

Sept. 19, 1933. E. F. ZAPARKA 1,927,538

SUSTAINING AND CONTROL SURFACE

Filed March 1, 1930 10 Sheets-Sheet 9

Fig. 25.

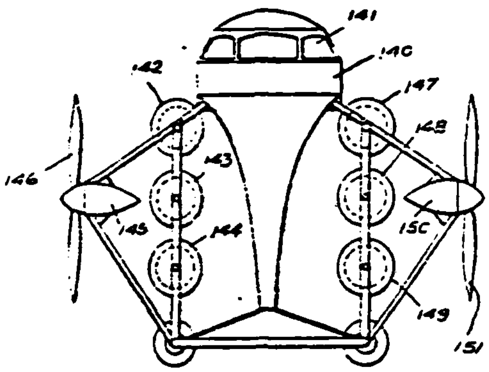


Fig. 26.

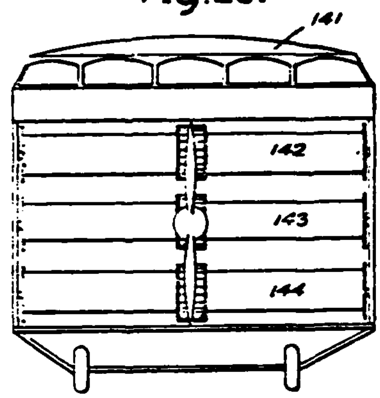


Fig. 27.

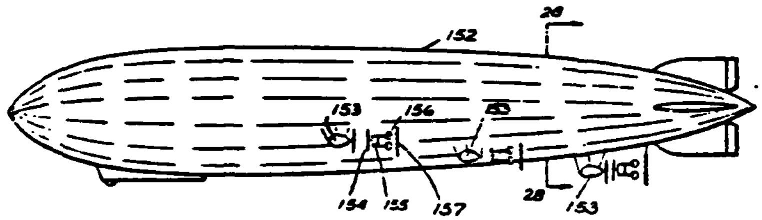


Fig. 28.

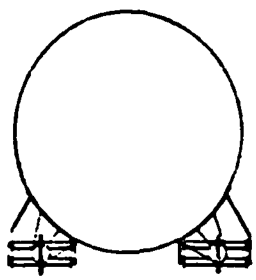
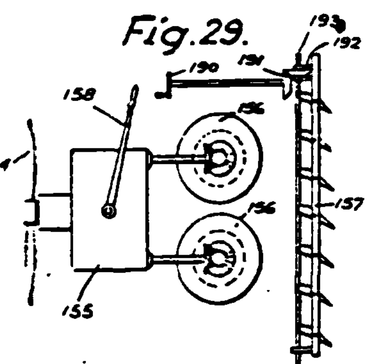


Fig. 29.



INVENTOR

Edward F. Zaparka

BY Duell, Dunn & Anderson

ATTORNEYS.

Sept. 19, 1933. E. F. ZAPARKA 1,927,538

SUSTAINING AND CONTROL SURFACE

Filed March 1, 1930 10 Sheets-Sheet 10

Fig. 30.

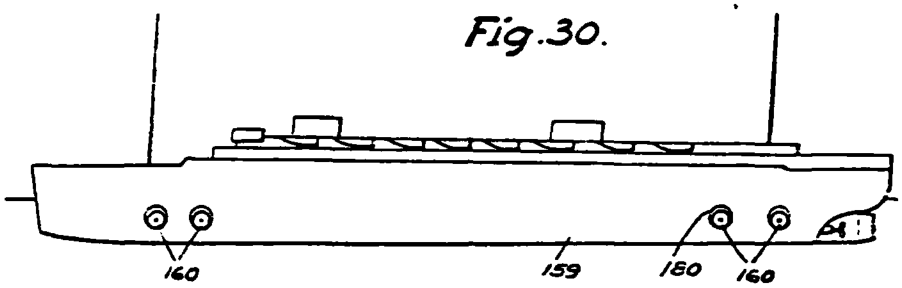


Fig. 31.

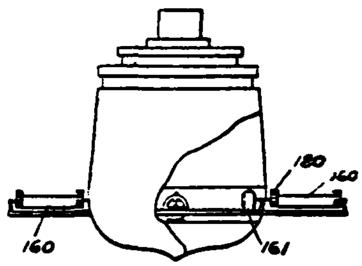


Fig. 35.

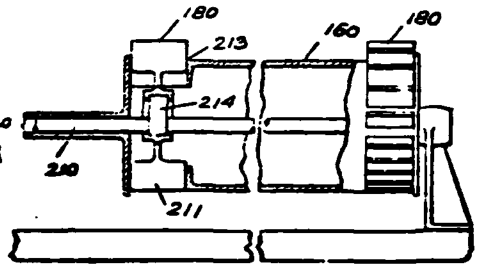


Fig. 32.

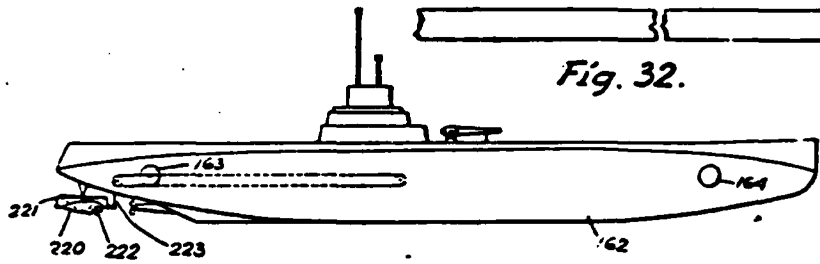


Fig. 33.

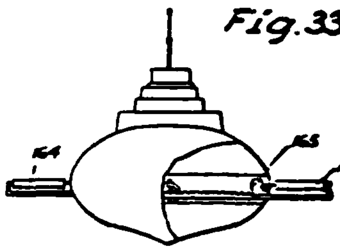
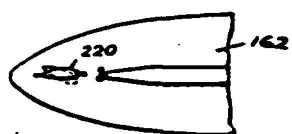


Fig. 34.



INVENTOR

Edward F. Zaparka

BY

ATTORNEYS

H.J. BINKS, SUPPORTING SURFACES FOR AIRCRAFT, U.S. PATENT 1,930,380
ISSUED OCTOBER 10, 1933

The invention is another version of the autohelirotor, with rotors mounted beneath the wings of a monoplane. The rotors have buckets at their tips and are impelled by the propeller slipstream.

- Figures 1 and 2 show a friction table drive to provide rotor spin and a worm gear to disengage the friction drive.

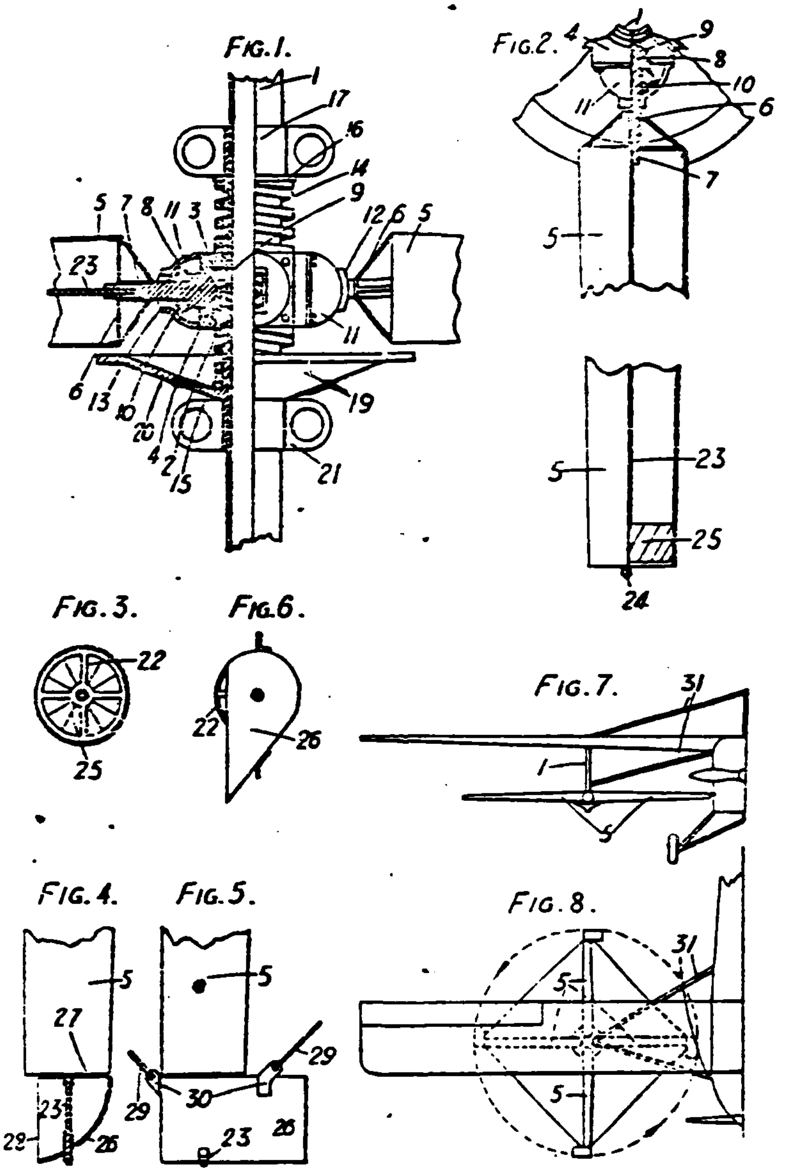
- Figures 7 and 8 show how the assemblies are to be installed on the plane.

ASSESSMENT: The device is of little value to modern aviation and probably would not have contributed much lift because of the low peripheral velocity of the rotors.

Oct. 10, 1933. H. K. BINKS 1,930,380

SUPPORTING SURFACES FOR AIRCRAFT

Filed Sept. 15, 1932



INVENTOR
Herbert K. Binks
BY
Chas. J. Williamson
ATTORNEY

R.K. LEE ET AL., PROPELLER, U.S. PATENT 1,977,681, ISSUED OCTOBER 23, 1934

Mr. Lee's invention is a Magnus effect propeller for aircraft featuring both mechanical and hydraulic rotor drive options and a variable rotor speed capability. The hub arrangements are clever and deserve a close look. (Note that Mr. Zaparka is involved as co-inventor.) The design does not call for the well-known end plates so the rotors would not be able to develop their full potential lift. The bevel gear system is similar to the Jensen propeller (see page 13).

- Figure 1 is a frontal view of the propeller installed on an airplane.

- Figure 2 is a sectional view along line 2-2 of Figure 1 showing the bevel gears and Figure 3 is a frontal section along line 3-3 of Figure 2. The propeller shaft (item 18) passes through a bearing (items 21, 22 and 23) fixed to the aft bevel gear plate (item 24) which is in turn bolted to the front of the engine by studs (item 33) so this subassembly cannot rotate. The rotor blade hub is free to turn on the shaft. The forward bevel gear (item 26) is splined to the propeller shaft and causes the rotors to spin. The rotor gears impinge on the aft, fixed bevel gear causing the whole propeller to revolve.

- Figure 4 shows a similar hub except that the aft bevel gear is held by a brake (items 52, 53 and 54) which can be released to disengage the propeller. This modification also calls for tapered rotors.

- Figure 5 shows how the rotors could be spun by compressed air or other fluids.

- Figure 7 shows a vent for the expended compressed air.

- Figure 6 is a cross-sectional view along line 6-6 of Figure 5.

ASSESSMENT: The various rotor drives of this invention are somewhat sophisticated and some elements may be suitable for marine use.

Oct. 23, 1934. R. K. LEE ET AL 1,977,681

PROPELLER

Filed Sept. 19, 1932 2 Sheets-Sheet 1

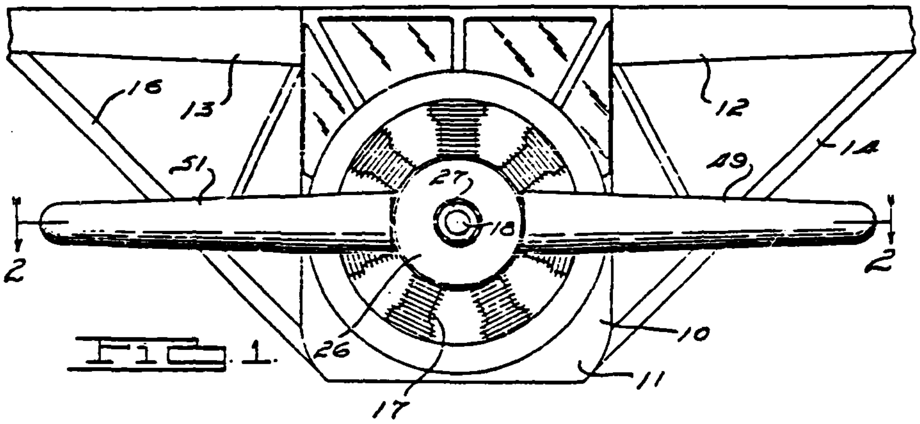


FIG. 1.

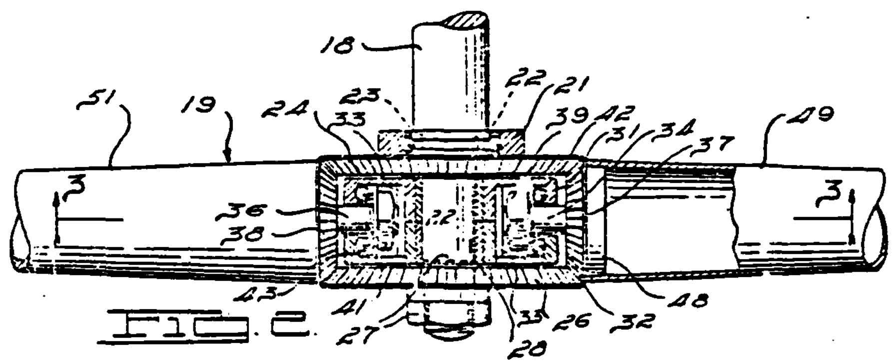


FIG. 2.

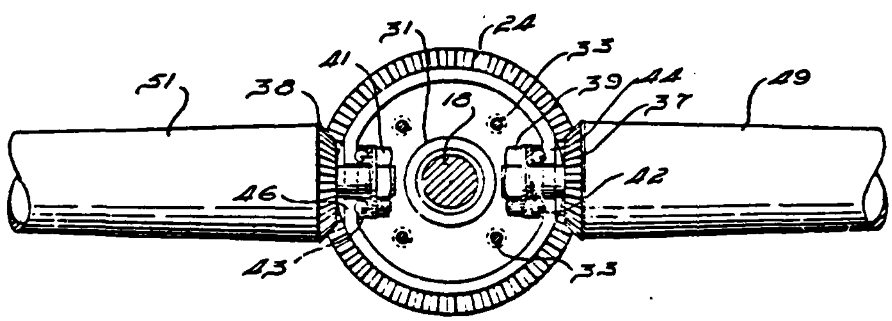


FIG. 3.

INVENTORS
Roger K. Lee.
Edward F. Zaparka.
BY
Harness, Dickey, Pierce & Hann
ATTORNEYS.

Oct. 23, 1934. R. K. LEE ET AL 1,977,681

PROPELLER

Filed Sept. 19, 1932 2 Sheets-Sheet 2

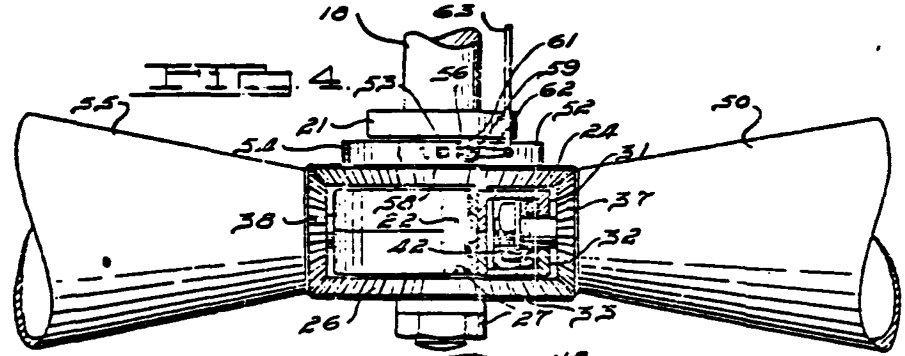


FIG. 4.

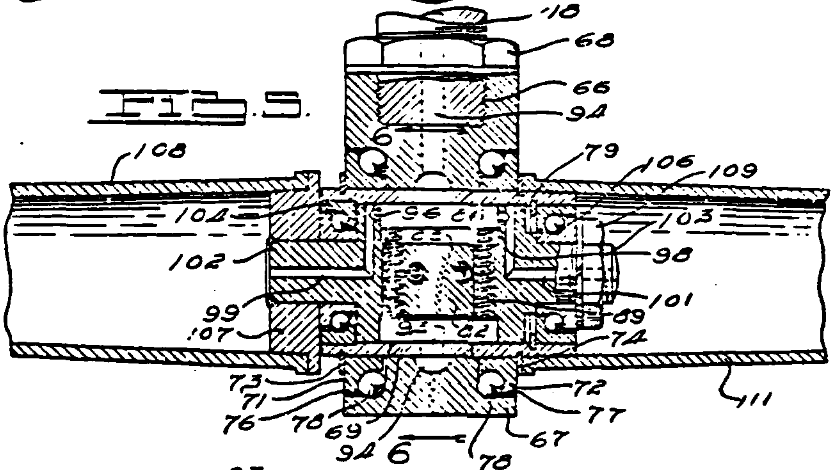


FIG. 5.

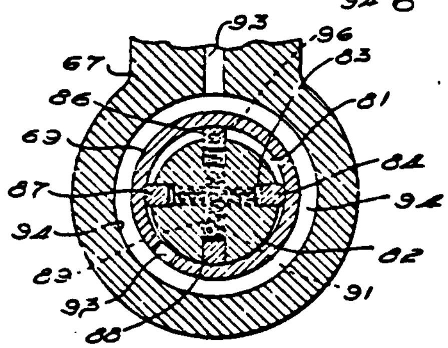


FIG. 6.

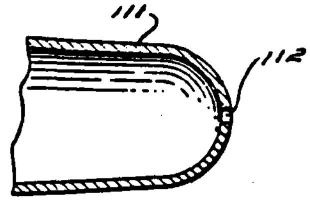


FIG. 7.

INVENTORS.
Roger K. Lee,
Edward F. Zaparka.
BY
Hanes, Dickey, Pierce & Hann
ATTORNEYS.

E.F. ZAPARKA, AIRCRAFT, U.S. PATENT 2,039,676, ISSUED MAY 5, 1936

Mr. Zaparka's third patent covers some Magnus effect applications for aircraft.

- Figures 1, 2 and 3 show a Magnus effect sustaining element which uses virtually the entire slipstream of a propeller. In this arrangement only the uppermost roller could actually produce any lift; the lower two would be interferred with by the high pressure from its underside.

- Figures 4 through 8 show various "deflecting surfaces," but these look to be the same as H. Fritzel's "guide bodies for reaction motors" patented in 1927.

- Figures 9, 10, 11 and 12 are rotors with drive details and control surfaces. Figure 13 is a side view of a triple rotor assembly with worm gear drive and movable deflectors.

- Figures 14 and 14A relate to a vertical aileron invention.

- Figures 15 and 16 show the rotors installed on a slope. This would work better than the vertical stack shown previously.

- Figures 17 and 18 are of a single turbine driven rotor with all control surfaces attached.

ASSESSMENT: This patent seems to be full of impractical Magnus effect schemes and no ideas of great value are evident.

May 5, 1936. E. F. ZAPARKA 2,039,676

AIRCRAFT

Filed Sept. 12, 1933 7 Sheets-Sheet 1

Fig. 1

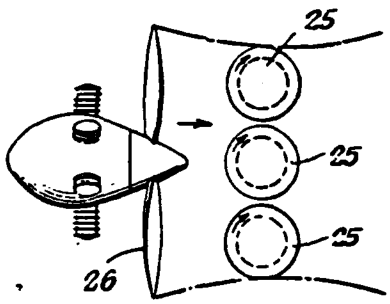
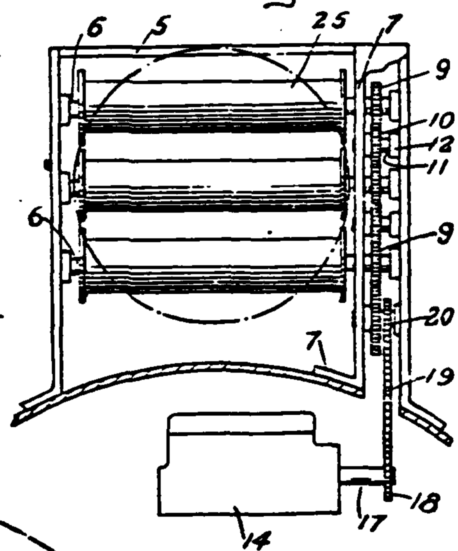


Fig. 2



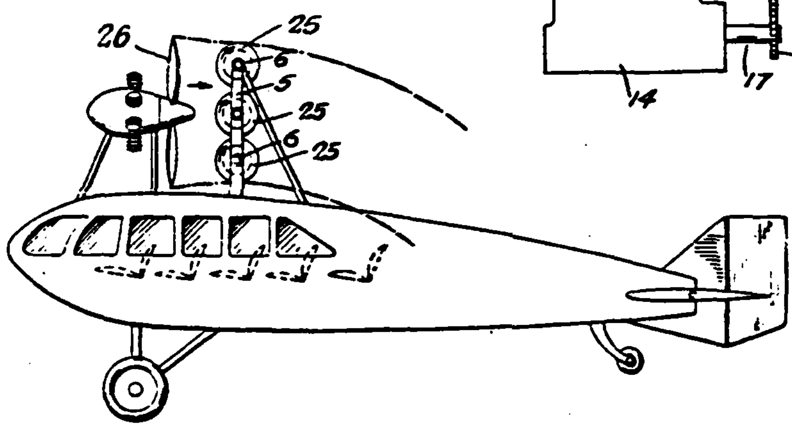


Fig. 3

INVENTOR

Edward F. Zaparka

Baulton, Whitcomb & Davies

ATTORNEYS

May 5, 1936. E. F. ZAPARKA 2,039,676

AIRCRAFT

Filed Sept. 12, 1933 7 Sheets-Sheet 2

Fig. 4

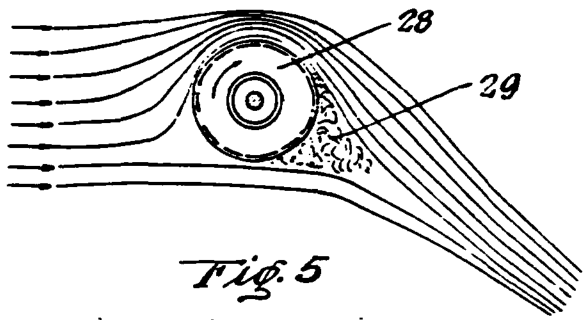


Fig. 5

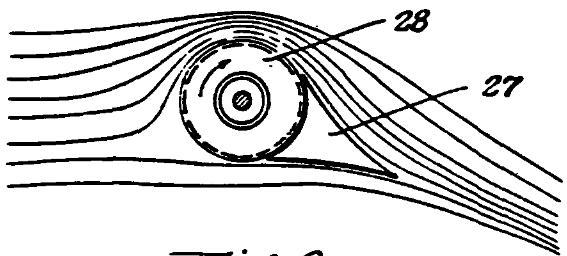
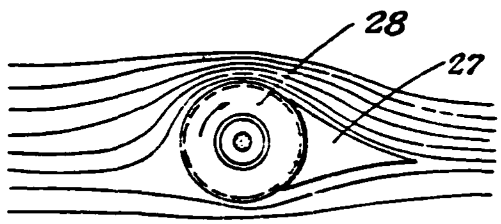


Fig. 6



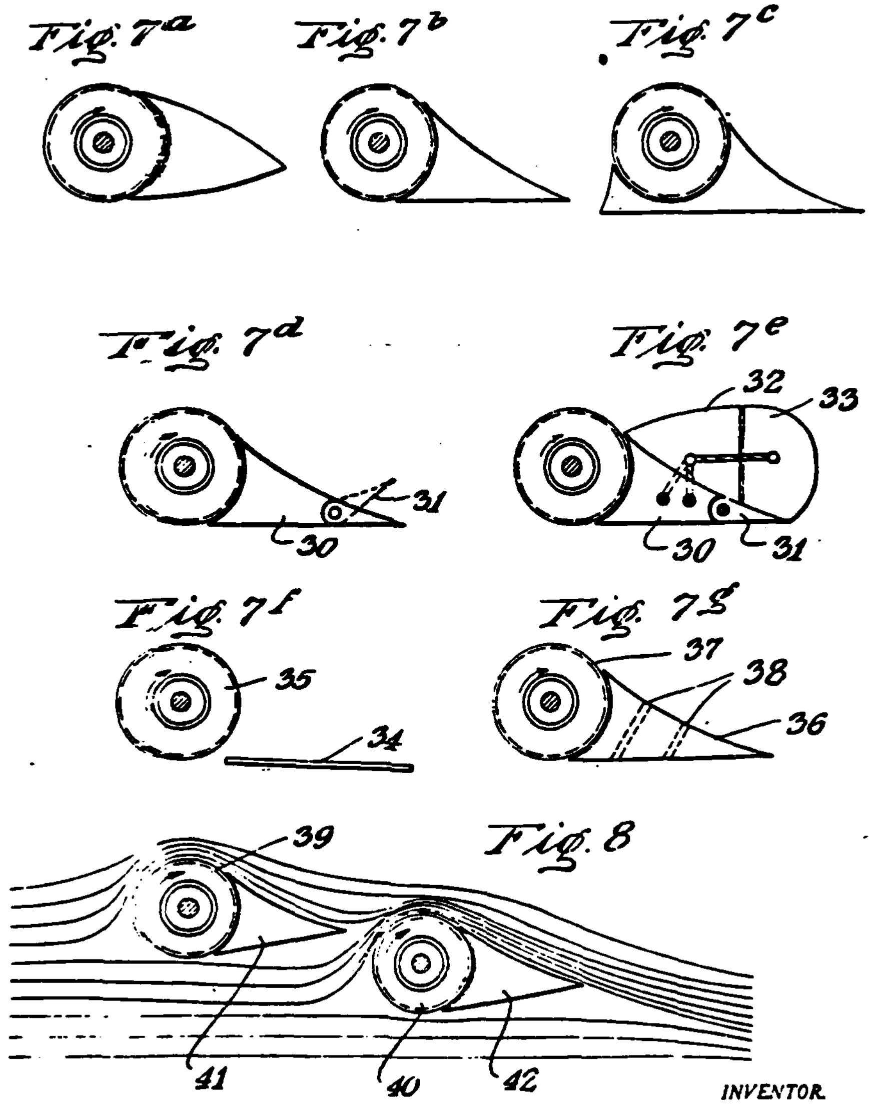
INVENTOR
Edward F. Zaparka

BY
Brandon, Whitcomb & Davis
ATTORNEYS.

May 5, 1936. E. F. ZAPARKA 2,039,676

AIRCRAFT

Filed Sept. 12, 1933 7 Sheets-Sheet 3



INVENTOR.
Edward F. Zaparka
BY
Braselton, Whitcomb & Davies
ATTORNEYS.

May 5, 1936. E. F. ZAPARKA 2,039,676

AIRCRAFT

Filed Sept. 12, 1933 7 Sheets-Sheet 4

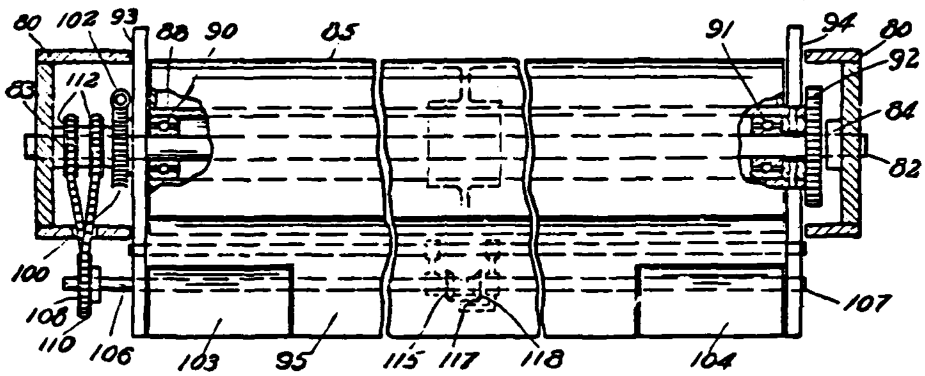


Fig. 9

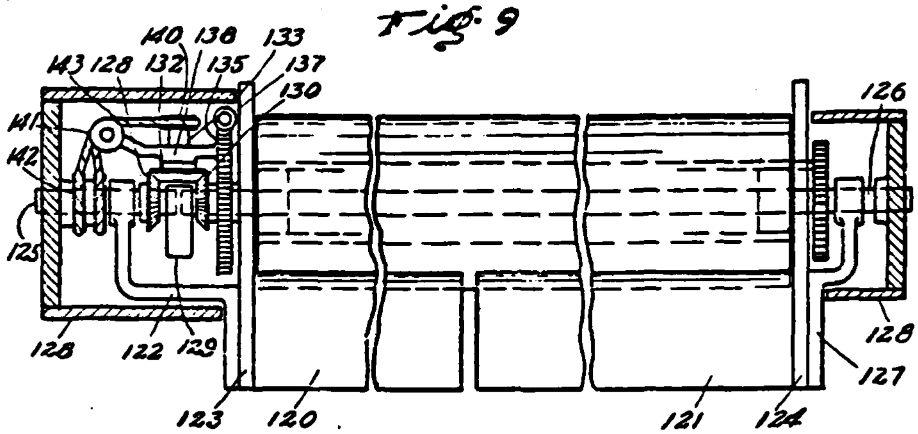


Fig. 10

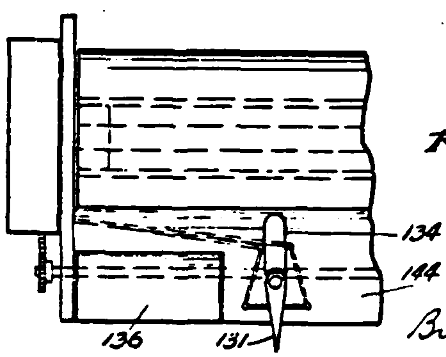


Fig. 11

INVENTOR

Edward F. Zaparka

BY

Brantton, Whitcomb & Davies

ATTORNEYS.

AIRCRAFT

Filed Sept. 12, 1930 7 Sheets-Sheet 5

Fig. 12

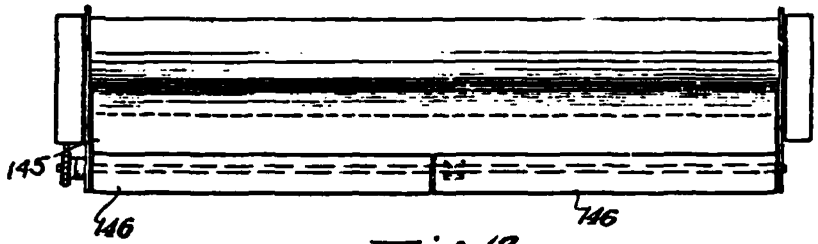
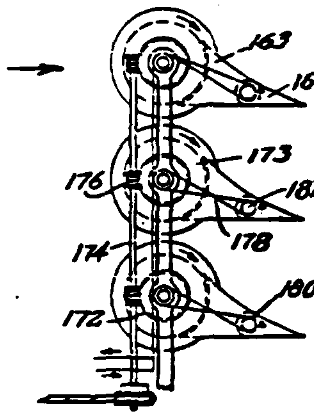


Fig. 13



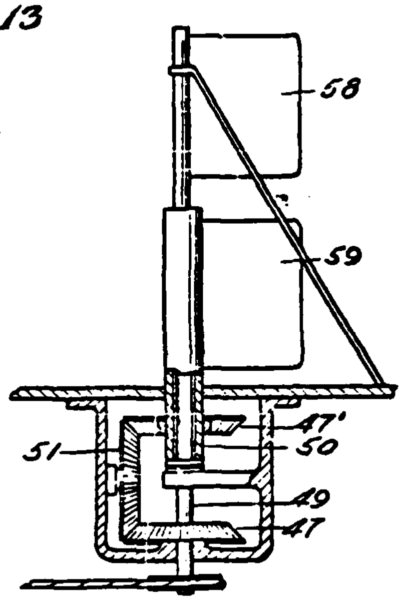
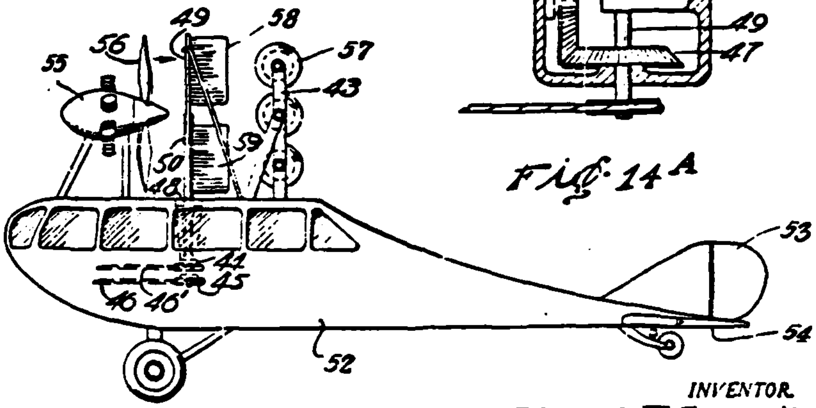


Fig. 14A



INVENTOR.
Edward F. Zaparka

Fig. 14

BY Bradley, Whitcomb & Davies
ATTORNEYS.

AIRCRAFT

Filed Sept. 12, 1933 7 Sheets-Sheet 6

Fig. 15

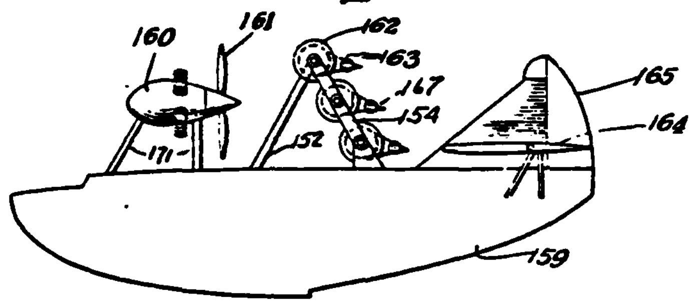
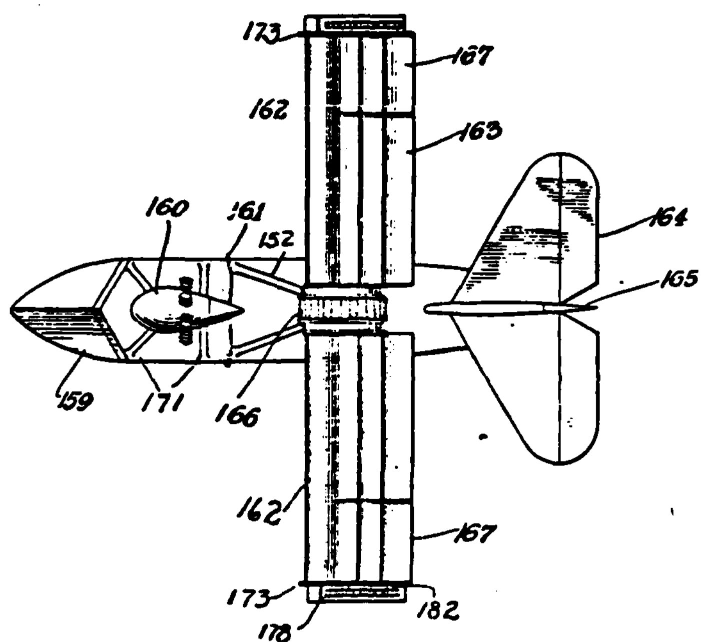


Fig. 16



INVENTOR
Edward F. Zaparka
BY Brastow, Whitcomb & Davis
ATTORNEYS.

May 5, 1936.

E. F. ZAPARKA

AIRCRAFT

Filed Sept. 12, 1933

2,039,676

7 Sheets-Sheet 7

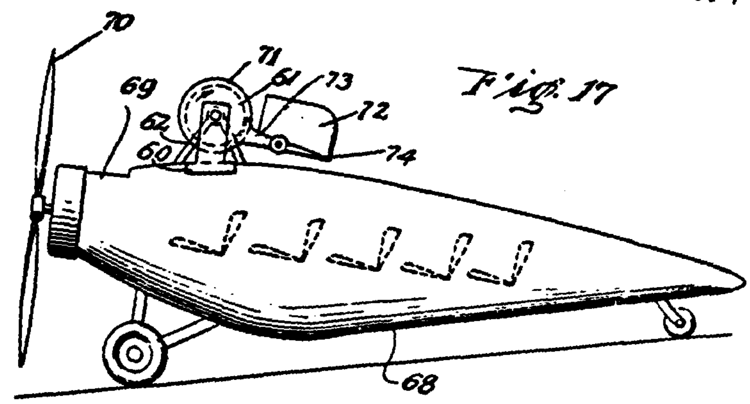


Fig. 17

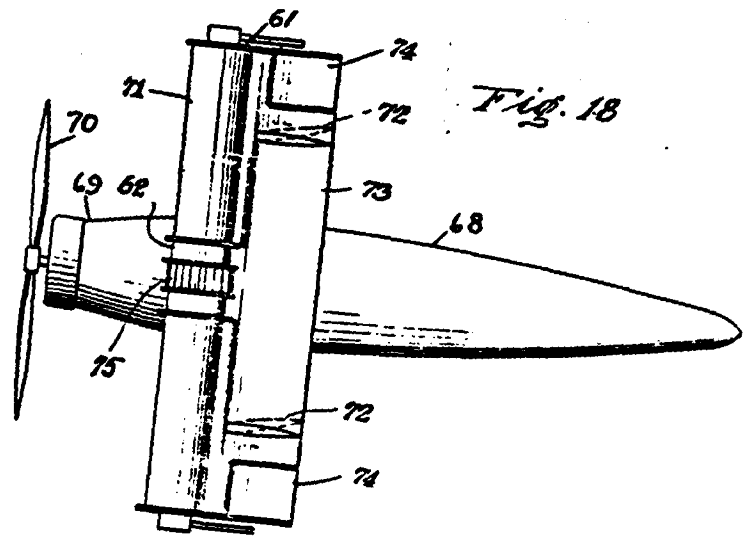


Fig. 18

INVENTOR
Edward F. Zaparka
BY
Braselton, Whitcomb Davies
ATTORNEYS.

P.C. GROSE, AIRCRAFT UTILIZING MAGNUS EFFECT, U.S. PATENT 2,417,358, ISSUED MARCH 11, 1947

The Grose invention is an excellent way to utilize the Magnus effect without paying the drag penalty associated with rotary wings. The lifting capabilities of the arrangement is significant (at least mathematically).

- Figures 1 and 2 respectively are a side elevation and a plan view of conventional aircraft fitted with longitudinally desposed rotors. Air is forced across them from within the fuselage producing a vertical ascent capability.

- Figure 3 is a two-rotor and Figure 4 is a four-rotor system both having a central impeller on a vertical shaft.

- Figure 5 is a perspective view of the four-rotor unit. Air is drawn down through the central opening by the impeller and is forced out around the rotors causing lift. If the intake hole could be shrouded in such a way as to cause a strong air-flow across the top surface of the box structure, additional lift would be generated by the pressure drop.

- Figure 6 illustrates the simple drive components for the rotors.

ASSESSMENT: Although the Gross invention may never be used on V.T.O.L. aircraft, it is a strong candidate in the realm of surface effect vessels. This idea should be more thoroughly studied with Naval applications in mind.

March 11, 1947. P. C. GROSE 2,417,358

AIRCRAFT UTILIZING MAGNUS EFFECT

Filed Aug. 3, 1942 2 Sheets-Sheet 1

FIG. 1.

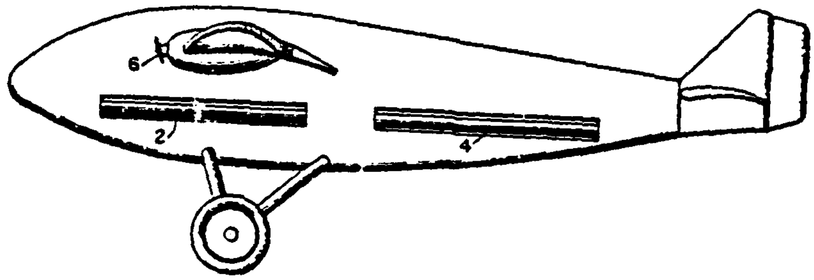
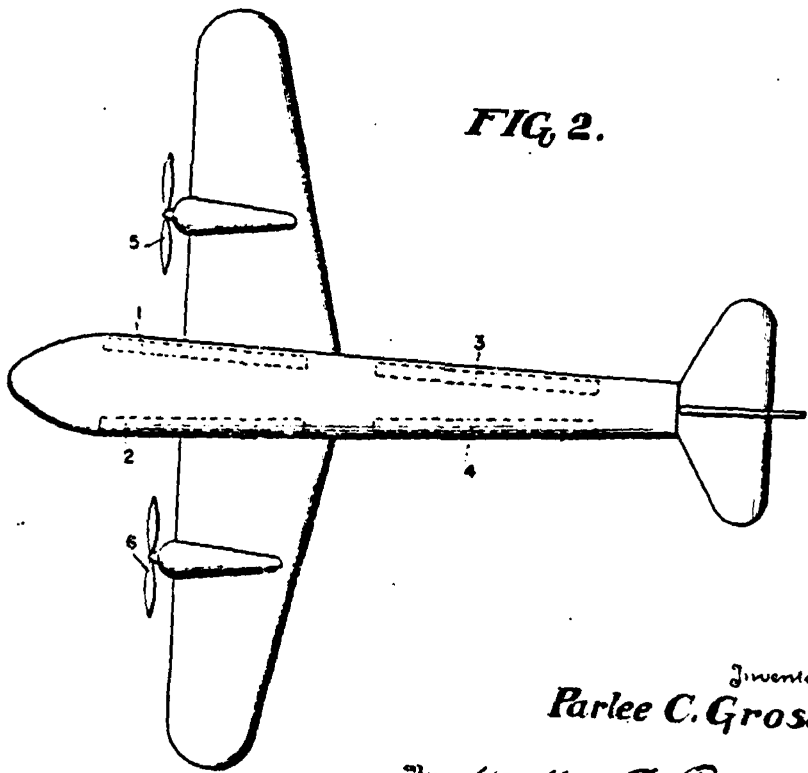


FIG. 2.



Inventor
Parlee C. Grose

By Wilfred E. Lawson
Attorney

AIRCRAFT UTILIZING MAGNUS EFFECT

Filed Aug. 3, 1942 2 Sheets-Sheet 2

FIG. 3.

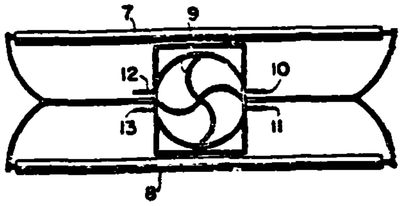


FIG. 4.

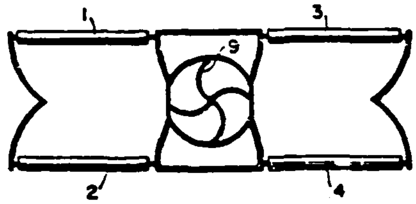
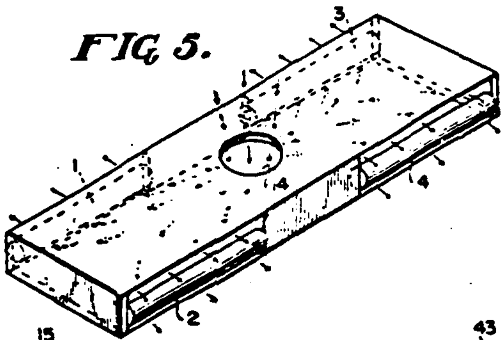


FIG. 5.



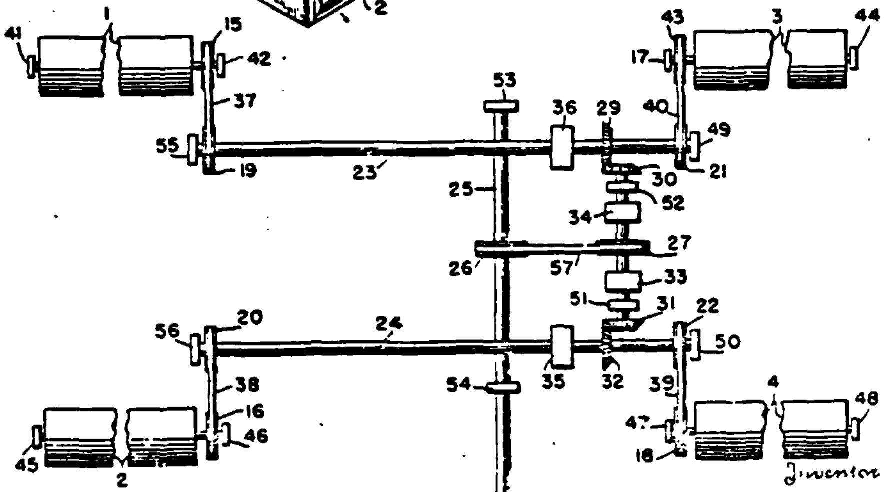


FIG. 6.

Inventor

Parlee C. Grose

By Wilfred E. Lawson

Attorney

J.N. CHANDLER, TORQUE CONTROL FOR HELICOPTER, U.S. PATENT 2,452,355, ISSUED OCTOBER 26, 1948, ASSIGNED TO THE BORG-WARNER CORPORATION

Chandler's torque control invention looks like a very practical use for the Magnus effect. The device consists of a cylindrical barrel tail for a helicopter in place of the current conventional asymetrical (and very vulnerable) tail rotor. By controlling the barrel's surface velocity the pilot could steer the aircraft.

- Figures 1 and 2 are views of the rotor showing the air flow and forces diagrammatically.

- Figure 3 is an elevation partially in section of a helicopter fitted with the torque control device.

- Figure 4 shows the retractable end plates or flanges whose secondary function is to act as brakes to slow the forward motion of the aircraft.

ASSESSMENT: Excepting unknown effects of cross winds on the stability of the helicopter, there is no reason to think that the Magnus effect torque control system would not work.

Oct. 26, 1948. J. N. CANDLER 2,452,355

TORQUE CONTROL FOR HELICOPTERS

Filed Sept. 11, 1944 2 Sheets-Sheet 1

Fig. 1

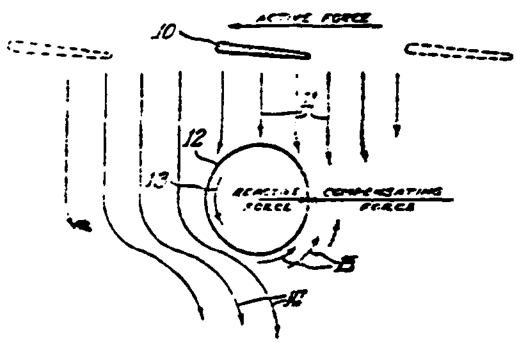


Fig. 2

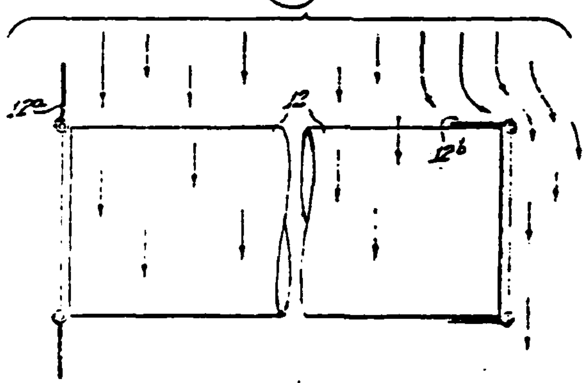
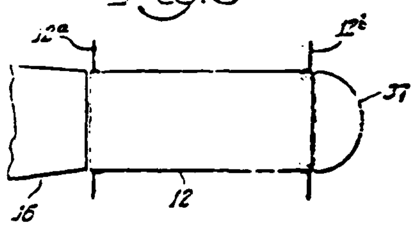


Fig. 5

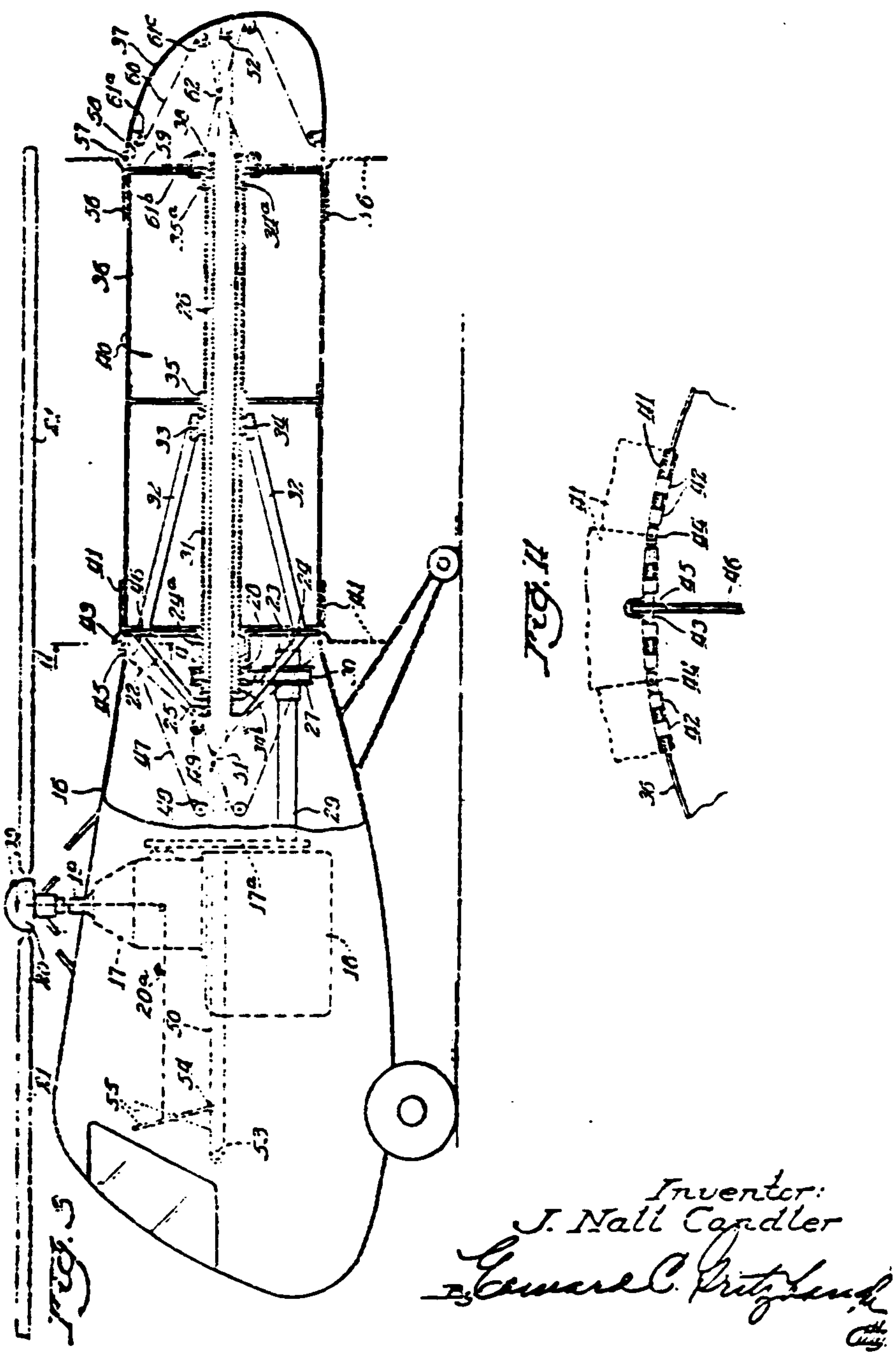


Inventor:
J. Nail Candler

Attorney

TORQUE CONTROL FOR HELICOPTERS

Filed Sept. 11, 1944 2 Sheets-Sheet 2



Inventor:
J. Nall Candler
By Edward C. Fitzgerald
Atty.

C. DUBOST, AERODYNAMIC LIFTING DEVICE, U.S. PATENT 2,532,899, ISSUED DECEMBER 5, 1950

In this patent, Mr. Dubost eliminates some of the inherent drawbacks in Magnus effect flight systems. The rotors are streamlined by mounting them atop a faired body, thus lowering drag resistance. An internal flywheel is provided to compensate for the gyroscopic effect of the rotors. The rotors are rotated by means of end-mounted turbines, simplifying the drive system; the exhausted gas is recycled to contribute to the flow around the rotors.

- Figure 1 is a diagrammatical section of a cylindrical rotor in a still atmosphere, showing the pressure zone formed around the moving periphery.

- Figure 2 is a curve illustrating the relation between the pressure and the distance from the periphery.

- Figure 3 is a diagrammatical section showing the action of an air draft on the location of the pressure zones around the rotor.

- Figure 4 is a transverse section of a rotor device showing a gutter (item 24) and a deflector (item 25).

- Figure 5 is a longitudinal section of the rotor.

- Figure 6 is a section of a device comprising a plurality of rotors.

- Figures 7 and 8 are plan and side views of Figure 6.

- Figures 9 and 10 are longitudinal sections of the rotor, Figure 10 shows the counterrotating flywheel subassembly (items 34 through 39).

- Figure 11 is a transverse section of another modification providing a horizontal propelling component.

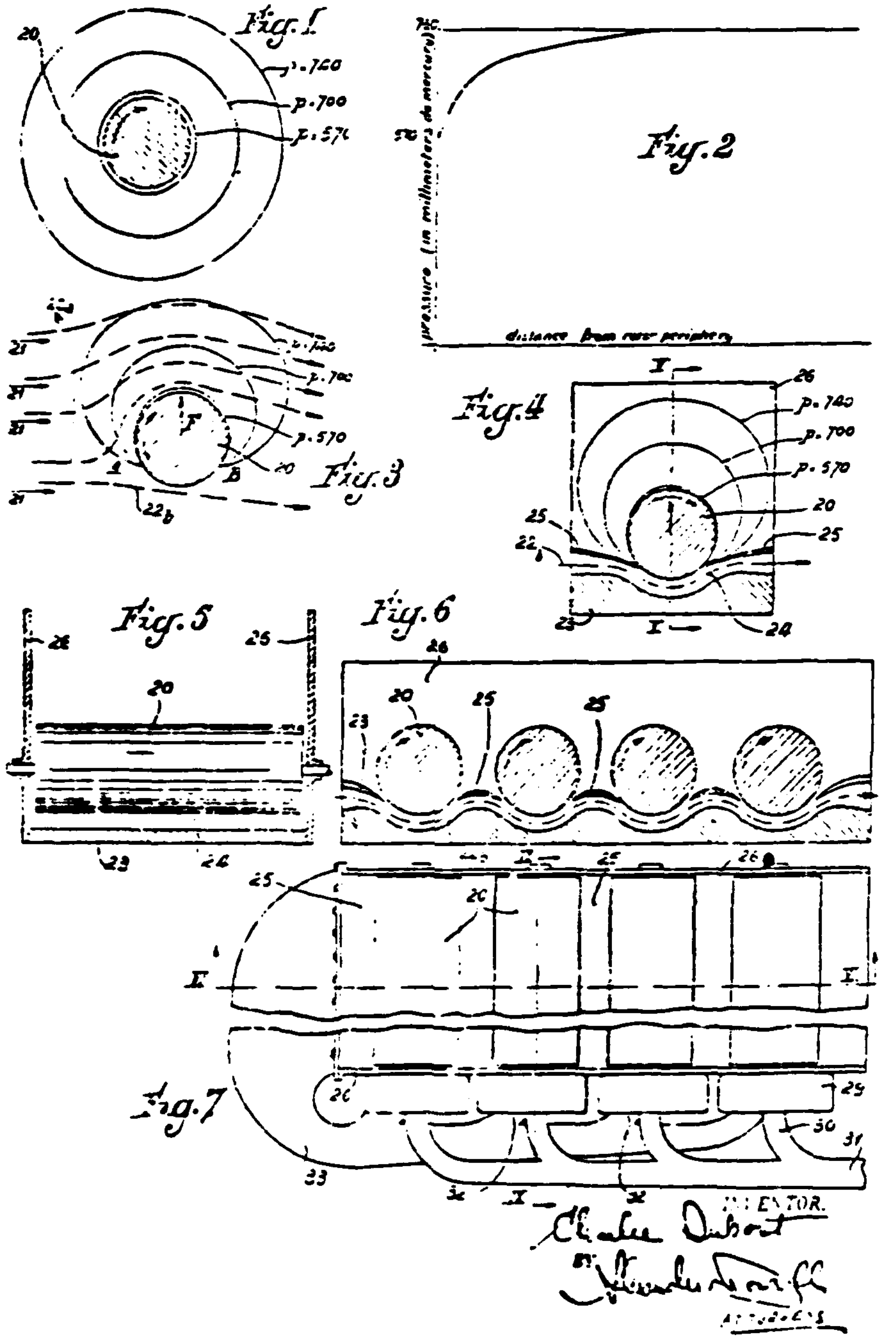
- Figure 12 is a longitudinal section of an aircraft embodying the sustaining device and Figure 13 is a transverse section through the aircraft.

ASSESSMENT: It is difficult to say if the Dubost machine is practical but the patent contains some ingenius elements that could be valuable in other Magnus effect devices.

Dec. 5, 1950 C. DUBOST 2,532,899

AERODYNAMIC LIFTING DEVICE

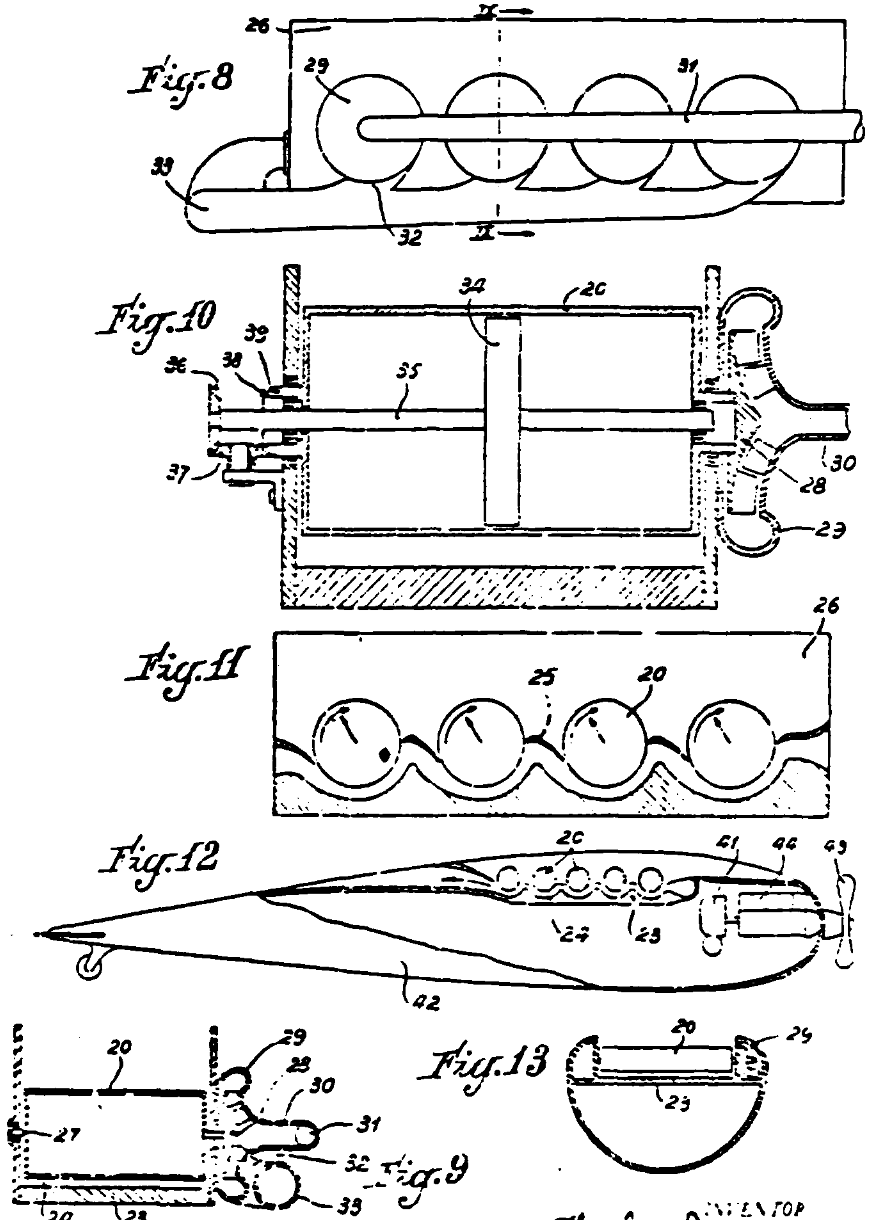
Filed Jan. 3, 1947 2 Sheets-Sheet 1



Dec. 5, 1950 C. DUBOST 2,532,899

AERODYNAMIC LIFTING DEVICE

Filed Jan. 3, 1947 2 Sheets-Sheet 2



INVENTOR
Charles Dubost
BY
ATTORNEYS

H.W. BUMP, AIRCRAFT SUSTAINED BY CYLINDRICAL ROTORS, U.S. PATENT 2,985,406, ISSUED MAY 23, 1961

The Bump patent is not a Magnus effect device in the strict sense but uses another form of boundry layer phenomena. The invention is based on the laws of behavior of vortices and in particular, the law that states that two adjacent counter-rotating vortices repel each other. In the Bump design, the vortices are created and held adjacent to each other so that the repellent forces from them are used as a means of propulsion.

- Figure 1 is a side elevation view of an aircraft fitted with double cylindrical wings capable of attitude adjustment.

- Figure 2 is a plan view of a partial cross section of the aircraft to show a drive arrangement.

- Figure 3 is an enlarged sectional view taken on the line 3-3 of Figure 2 showing a means for changing the attitude of the cylinders (items 58, 60 and 62) and a deflector baffle (item 32).

- Figures 4 and 5 are diagrammatical views showing two positions of pivotal adjustment of the cylinder assembly.

- Figure 6 is an enlarged sectional view taken along line 6-6 in Figure 2 showing the gearbox (item 20) and other aspects of the full cylinder assembly.

- Figure 7 is a fragmentary sectional view of a second embodiment of the invention and Figure 8 is a view taken along line 8-8 in Figure 7.

This second embodiment carries a plurality of closely spaced disks along each cylinder and a toothed deflector. It is intended to be used on an aircraft having a conventional fixed wing.

As an illustration of the functionality of the smooth cylinder assembly, assume that the cylinders are approximately 36 inches in diameter and have a circumference of over 100 inches. As the boundry layer builds up to about one-inch per 100 linear inches, each cylinder will deliver a flow of 12 cubic inches per linear foot. At a peripheral velocity of the speed of sound, such a flow of air will produce a pressure of approximately 25 pounds per square inch and this would be 300 pounds per linear foot of cylinder or 100 pounds per square feet of cross section. The multiple disk variation of the invention using 36 inch diameter disks develops 600 pounds of lift per square foot of cross section.

ASSESSMENT: The lifting force developed by this device is impressive but in forward flight the Magnus effect would work against the forward rotor causing a loss of lift or a pitching moment. This was not considered by the inventor.

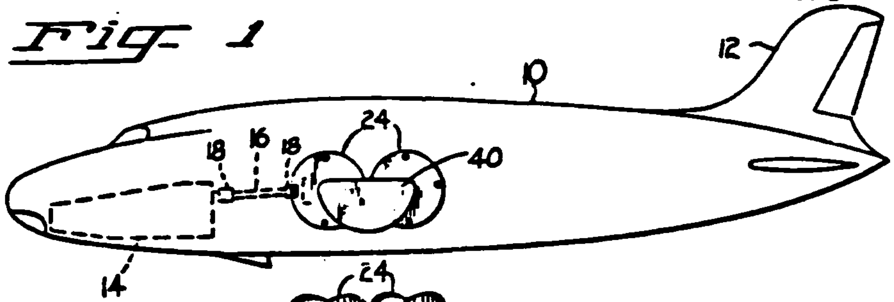
The concept might be applicable to ship propulsion. The twin cylinders could be employed as Magnus effect sails when rotating in the same way and could be quickly converted into a direct propulsion system using air as a medium by simply reversing the direction of one of the rotors. The horsepower requirements are low, making the system attractive for certain types of cargo vessels. It is conceivable that a dual rotor sail and propulsion system could be developed to such a degree of efficiency that the underwater propeller would be effectively eliminated.

May 23, 1961 H. W. BUMP 2,985,406

AIRCRAFT SUSTAINED BY CYLINDRICAL ROTORS

Filed April 29, 1959 2 Sheets-Sheet 1

Fig. 1



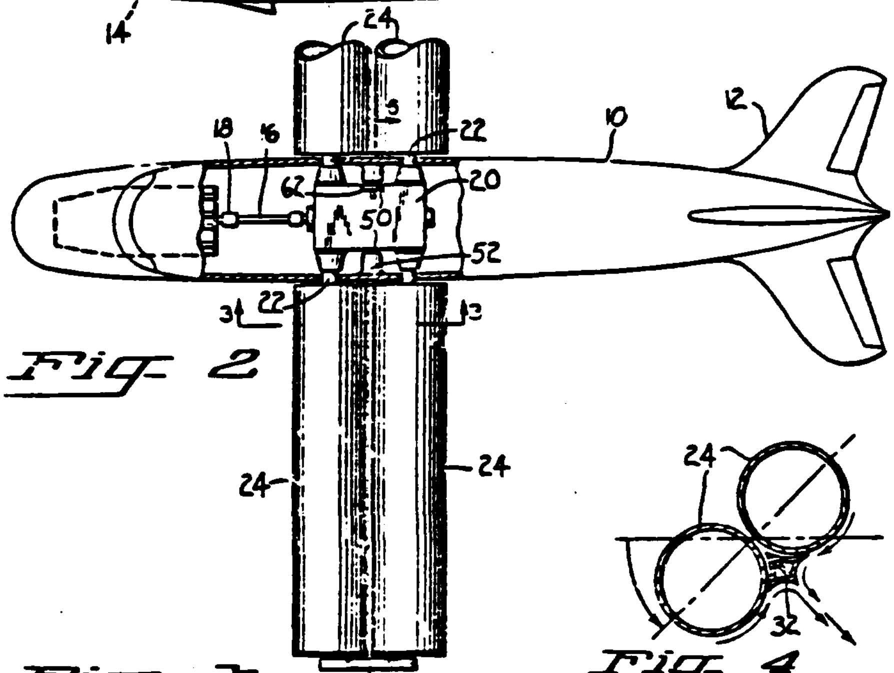


Fig. 2

Fig. 3

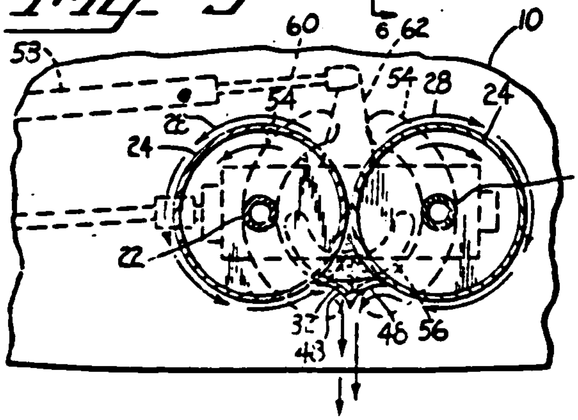


Fig. 4

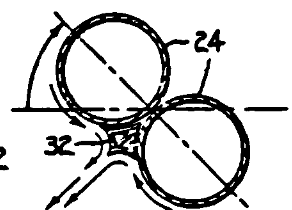


Fig. 5

INVENTOR.
HAROLD W. BUMP

BY Eugene M. Eckelman
ATTORNEY

AIRCRAFT SUSTAINED BY CYLINDRICAL ROTORS

Filed April 29, 1958 2 Sheets-Sheet 2

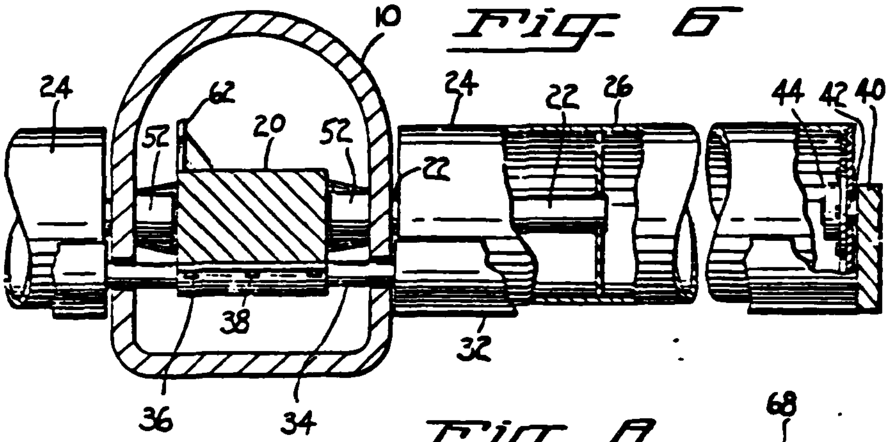


Fig. 6

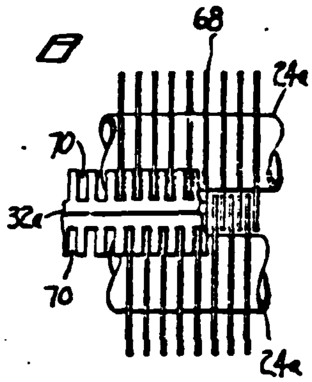


Fig. 8

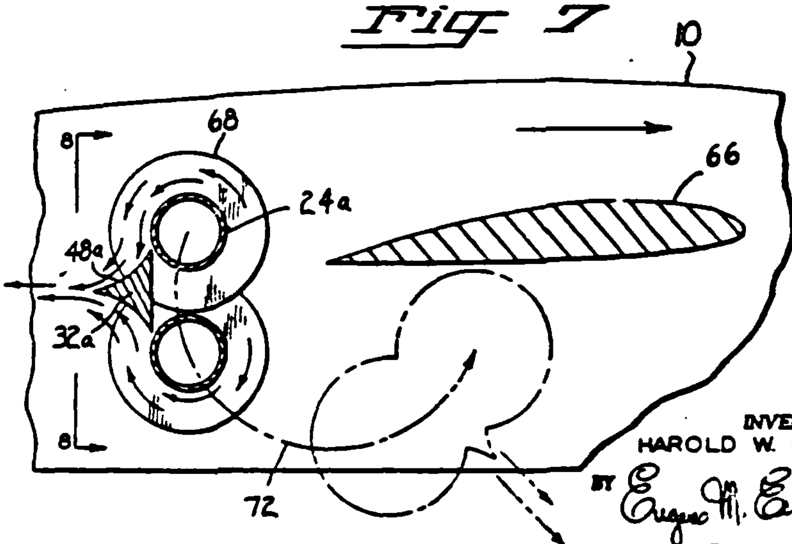


Fig. 7

INVENTOR
HAROLD W. BUMP
BY Eugene M. Edelman
ATTORNEY

K. PFLIEIDERER, ET AL, ROTOR CONSTRUCTION, U.S. PATENT 3,120,275 ISSUED FEBRUARY 4, 1964, ASSIGNED TO BOLKOW-ENTWICKLUNGEN KOMMAND-DITGESLLSCHAFT, OTTOBRUNN, NEAR MUNICH, GERMANY

This invention relates in general to aircraft construction and in particular to a rotor head for vertical flight use in an aircraft having additional means for horizontal flight. The improved rotor element construction combines a means for rotating the rotor elements and for permitting the extension and retraction of the rotor elements in the head. The invention is pertaining to flexible, retractable, Magnus effect helicopter rotors, extended by centrifugal force.

- Figure 1 is a fragmentary side elevation of a rotor head for a "convertaplane" having Magnus effect rotors for "blades".
- Figure 2 shows a rotor constructed of articulated elements and Figure 3 shows the rotor with a flexible covering.
- Figure 4 is a cross section through a rotor consisting of a plurality of loop elements which are bound to a central, flexible cable.
- In Figure 5 a hollow rotor construction is shown with a cover or reinforcement.
- Figure 6 shows an elevation of a version of a rotor head in which the flexible rotors are wound upon a vertical axis drum.
- Figures 7 and 8 are views of yet another modification in which the rotors are retracted upon individual drums in the horizontal plane.
- Figures 10, 11 and 12 show various arrangements for the rotor storage drums.

ASSESSMENT: While a greater portion of this patent deals with arrangements for retracting flexible rotors, the idea of a propeller with limp blade elements is in itself unique.

Feb. 4, 1964 K. PFLEIDERER ET AL 3,120,275

ROTOR CONSTRUCTION

Filed March 26, 1962 3 Sheets-Sheet 1

Fig. 1

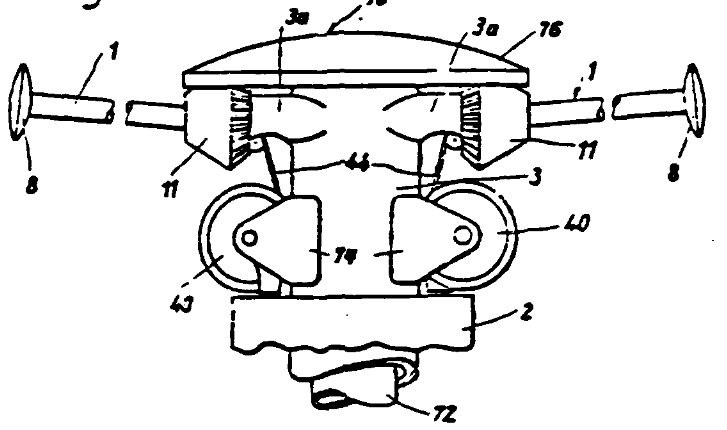


Fig. 3

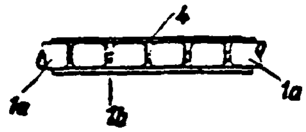


Fig. 2

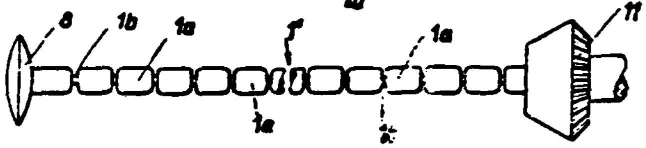


Fig. 4

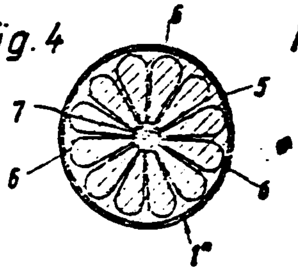
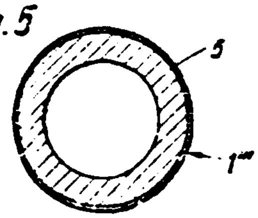


Fig. 5



Inventors
KURT PFLEIDERER
EMIL WEILAND
BY: McGlew and Toren
ATTORNEYS

Fig. 6

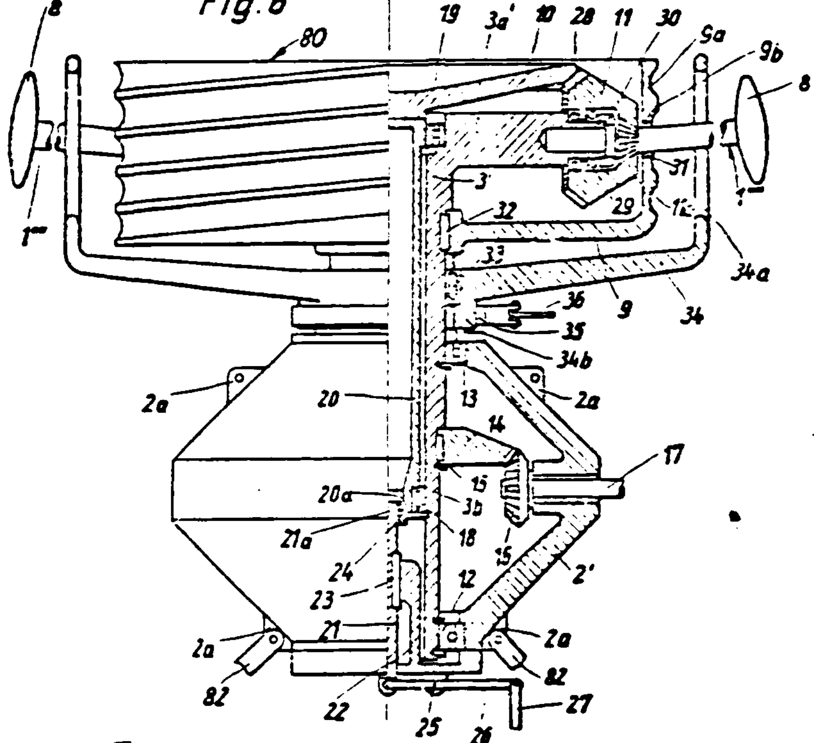


Fig. 11

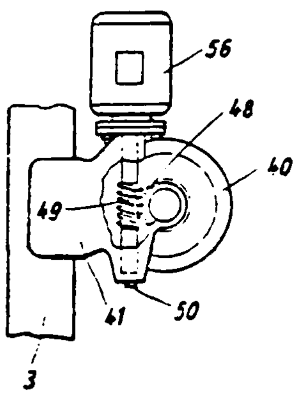
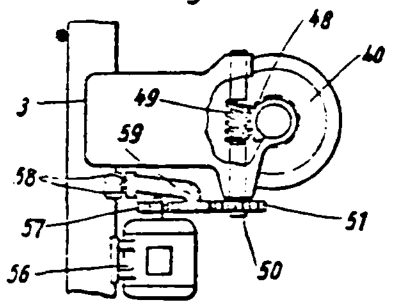


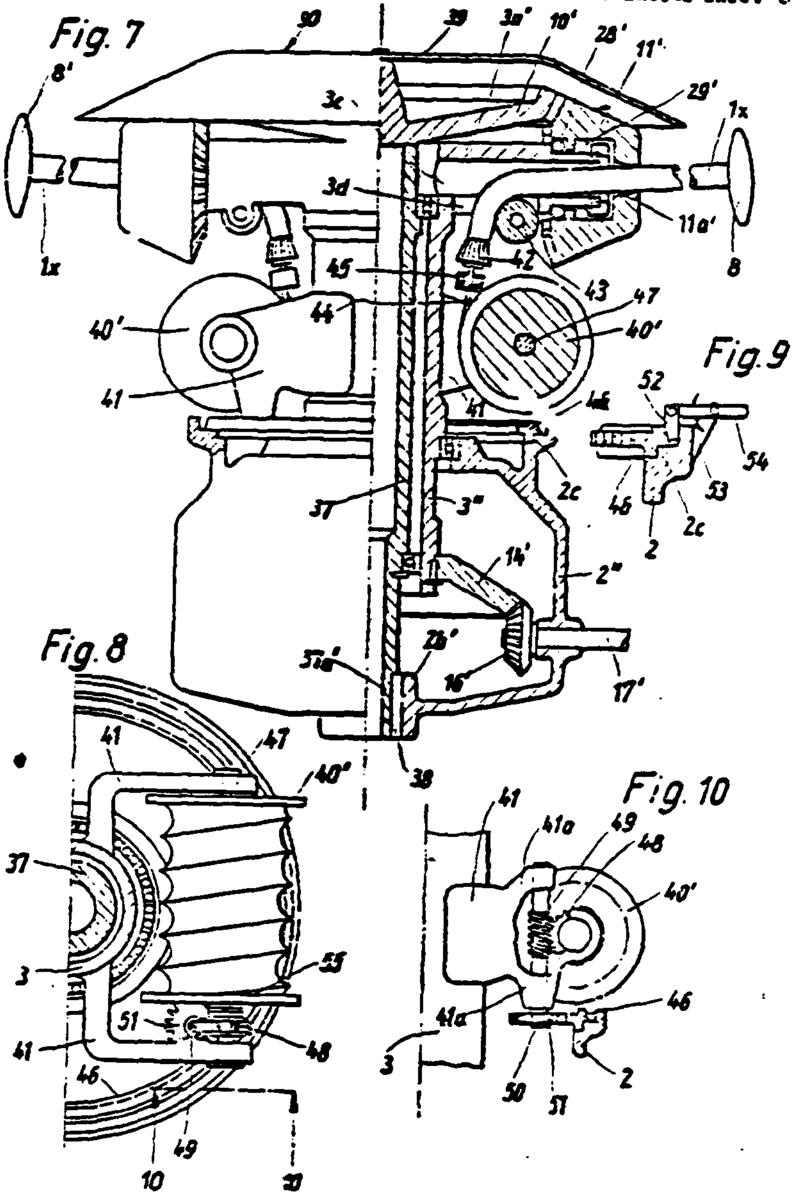
Fig. 12



Inventors:
KURT PFLEIDERER
EMIL WEILAND
BY: McGlew and Toren
ATTORNEYS

ROTOR CONSTRUCTION

Filed March 16, 1962 3 Sheets-Sheet 3



Inventors
KURT PFLEIDERER
EMIL WEILAND
BY: McGlew and Toren
ATTORNEYS

T. HOPWOOD, AIRCRAFT AND LIFT DEVICES THEREFOR, U.S. PATENT 3,162,401 ISSUED DECEMBER 22, 1964, ASSIGNED TO HAWKER SIDDELEY AVIATION, LTD., SURREY, ENGLAND

Hopwood's invention is a telescoping Magnus effect auxiliary lifting surface. It is extended and rotated by means of high pressure air through external intakes in the fuselage. The intent of the device is to overcome the problems of loss of lift and shift in centers of lift that occur when supersonic aircraft fly at low speed. The fact that the patent was assigned to Hawker-Siddeley Aircraft, Ltd. indicates that it may have been developed as part of the "Concorde" project.

- Figures 1 and 2 are views of the forward part of the aircraft showing the extended lifting surfaces.
- Figure 3 illustrates one of the lift devices in more detail as seen on the line 3-3 of Figure 1, the part of the Figure above the centerline showing the device extended and that below of showing it retracted.
- Figure 4 is a cross-section of one of the telescoping sections of a lift device taken on the line 4-4 of Figure 3.
- Figure 5 is a detail sectional view from the same viewpoint as Figure 3 but shows only parts of two telescoping sections that illustrate how they are arranged to slide one within the other.
- Figure 6 is a section on the line 6-6 of Figure 5.
- Figure 7 is a detail cross-sectional view of part of the skin structure of one of the sections.
- Figure 8 is a diagram illustrating how air is blown out around each lift device.

ASSESSMENT: This patent demonstrates another way to extend and rotate a telescoping sail.

Dec. 22, 1964 T. HOPWOOD 3,162,401

AIRCRAFT AND LIFT DEVICES THEREFOR

Filed Dec. 8, 1961 3 Sheets-Sheet 1

Fig.1

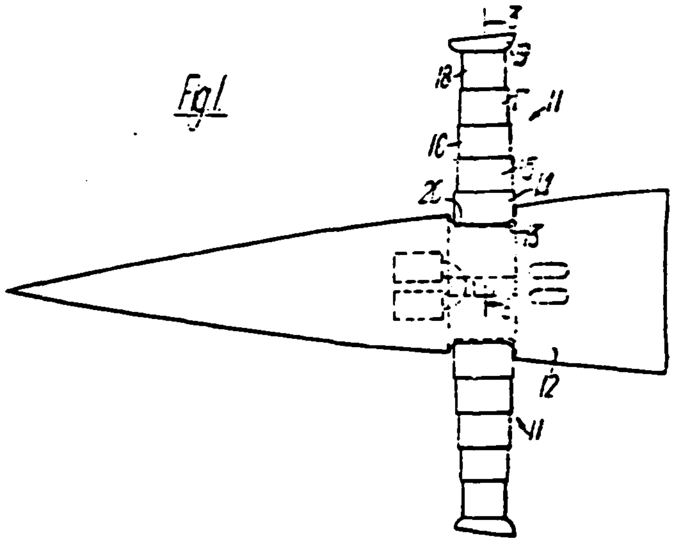
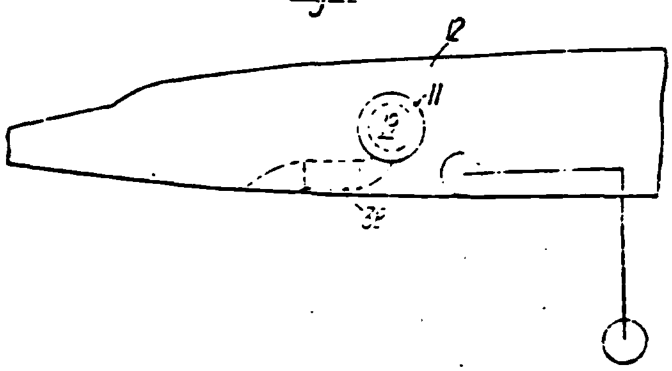


Fig.2

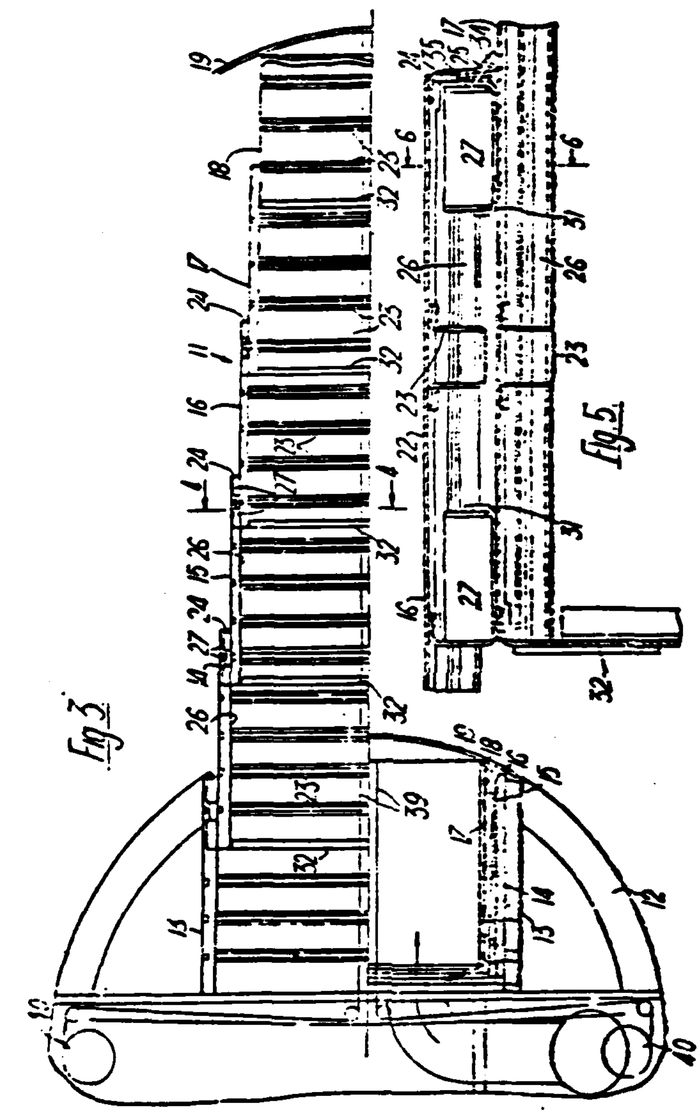


Inventor
Thomas Hopwood

Attorneys

AIRCRAFT AND LIFT DEVICES THEREFOR

Filed Dec. 8, 1961 3 Sheets-Sheet 2



Inventor
Thomas Hopwood

By
Attorneys

Fig. 4

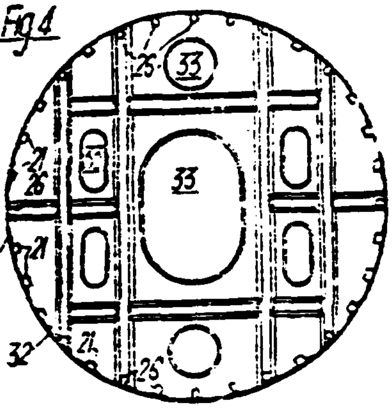


Fig. 6

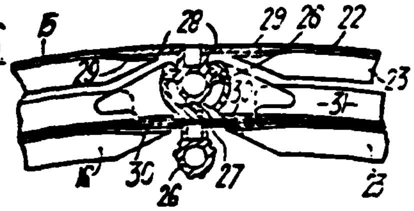


Fig. 7

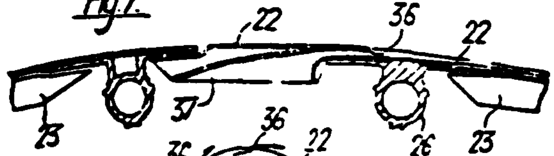
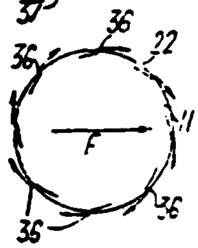


Fig. 8



Inventor
Thomas Hopwood

By
Dowell & Dowell
Attorneys

G.D. BOEHLER, ET AL, WING ROTORS, U.S. PATENT 3,262,656, ISSUED JULY 26, 1966 AND CONTINUATION, WING ROTOR CONTROL APPARATUS, U.S. PATENT 3,439,887, ISSUED APRIL 22, 1969. BOTH ASSIGNED TO AERO-PHYSICS COMPANY, WASHINGTON, DC

These patents relate to autorotating glider wings, their possible uses and means of maneuvering them.

Refering to the earliest patent (3,262, 656), Wing Rotors,

- Figure 1 shows the invention being launched from the rear doors of a cargo aircraft.

- Figure 2 is an enlarged plan view of a wing rotor with one end broken away to show diagrammatically the control mechanisms in the hollow interior of the structure.

- Figure 3 is a cross-section on the line 3-3 of Figure 2.

- Figure 4 is a perspective view of a modification of the invention in which it is adapted for towing behind another aircraft with a cargo carrying body suspended beneath the wing.

- Figure 5 is a perspective view of a further modification in which the wing rotor is adapted for use with a jettisonable fuselage or boom to function as the fixed wing of a towable glider, and convertable to operation as a wing rotor.

- Figure 6 is a perspective view similar to Figure 5 in which the wing structure assumes a conventional flying wing configuration permitting the elimination of the horizontal stabilizer surfaces on the boom.

- Figure 7 is an airfoil section adaptable to a wing rotor.

- Figure 8 shows the jettisonable connection.

- Figures 9A through 9D are a series of perspective views showing the in-flight conversion from fixed to rotor wing cylinder and subsequent controlled flight to a target area.

- Figures 10, 11 and 12 show the shift in center of gravity from fixed to rotor wing that enables the device to achieve Magnus effect flight.

- Figure 13 is an end elevation of the wing showing the addition of rockets for imparting power rotation to the wing.

- Figures 14 and 15 are enlarged diagrammatic views of the yaw control spoilers shown in Figure 2 showing the alternate actuation causing the wing to yaw in opposite directions.

- Figure 16 is an end elevaton showing the use of flyball weights for storing energy for power driving purposes.

Refering to the later patent (3,439,887), Wing Rotor Control Apparatus,

- Figure 1 is a perspective view of a wing rotor employing extensible drag inducing members.

- Figure 2 shows an end plate extender as a control method and Figure 2A is a detailed section of the same.

- Figure 3 is a perspective view showing pivotal, drag producing end plates and Figures 4 and 4A show another alternative of Figure 3.

- Figures 5, 6 and 7 are still more possible end plate controls.

ASSESSMENT: Model tests indicate that Mr. Boehler's wing rotor is, indeed, a good glider and the same section can be used for other applications such a windmill blades and sails. It is a tempermental self-starter, however, and sometimes needs a nudge to get going.

The use of autorotor wings in lieu of parachutes for cargo delivery is plausable. Their advantages are a better glide slope and ease of control although they would consume more space in a cargo plane.

July 26, 1966 G. D. BOEHLER ET AL 3,262,656

WING ROTORS

Filed Oct. 21, 1964 5 Sheets-Sheet 1

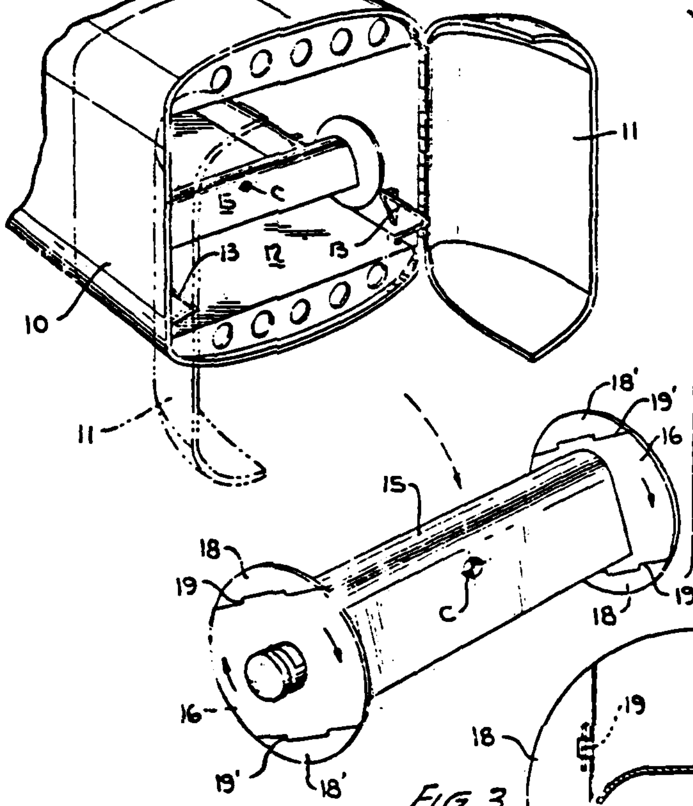


FIG. 1

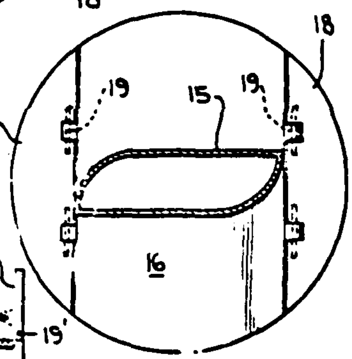
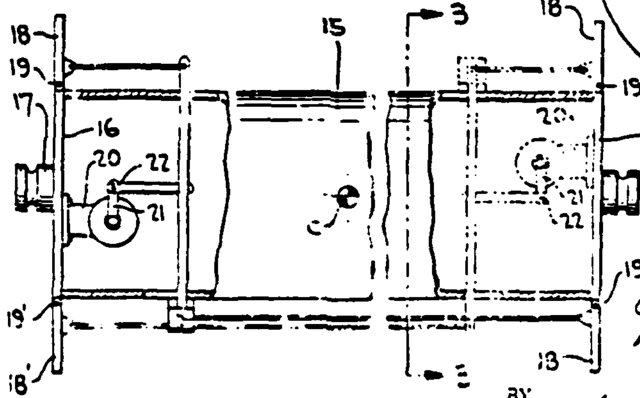


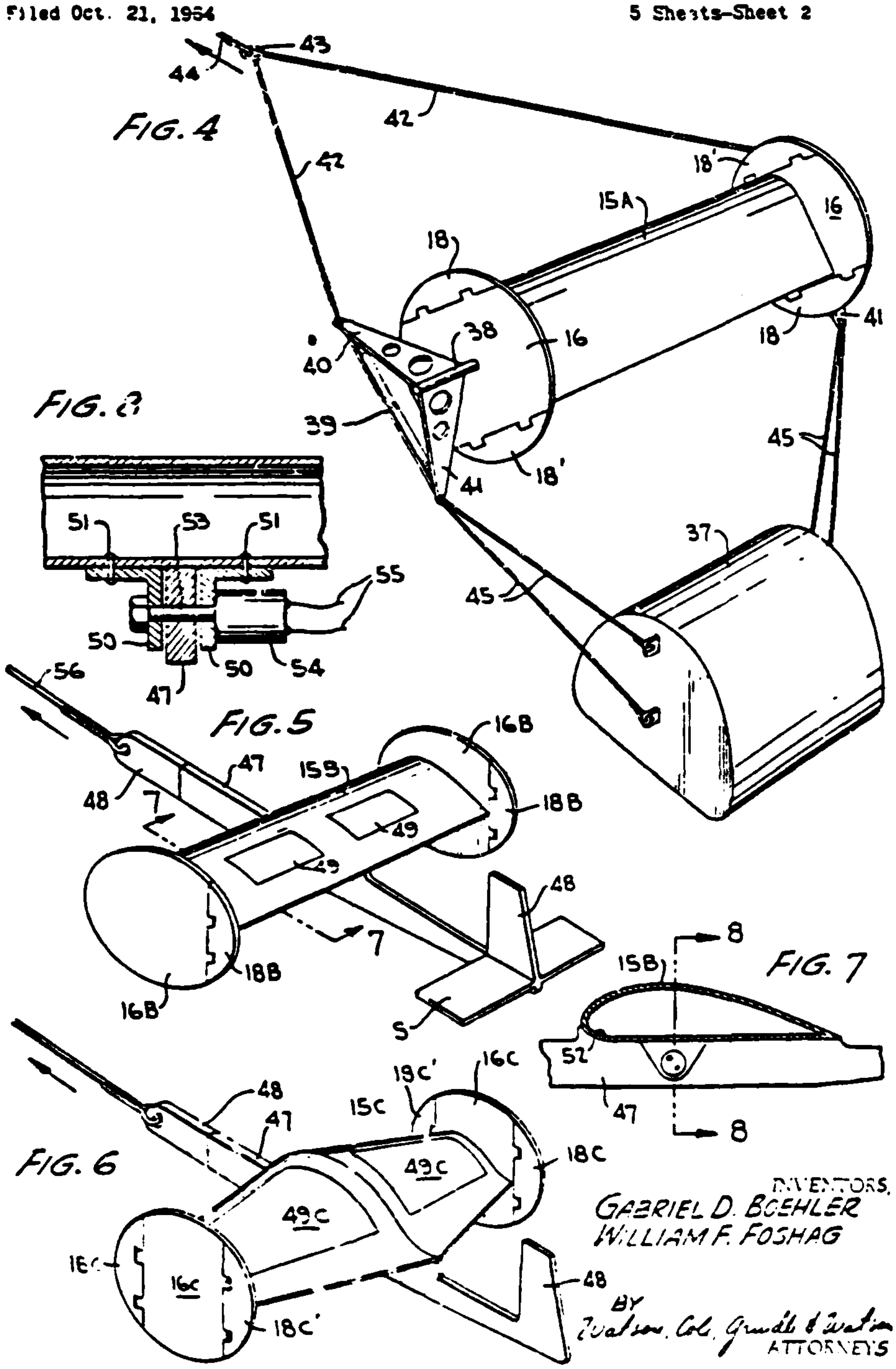
FIG. 3

FIG. 2



INVENTORS,
GABRIEL D. BOEHLER
WILLIAM F. FOSHAG

BY Watson, Cole, Grindle & Watson
ATTORNEYS



INVENTORS,
GABRIEL D. BOEHLER
WILLIAM F. FOSHAG

BY
Watson, Cole, Grindle & Watson
ATTORNEYS

FIG. 10

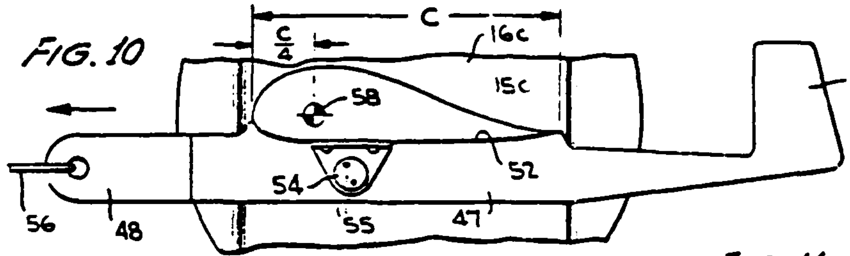


FIG. 11

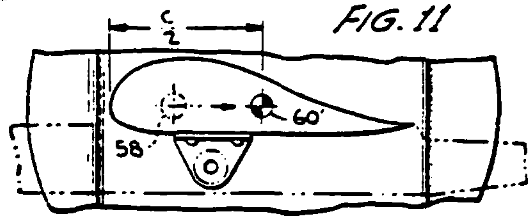


FIG. 12

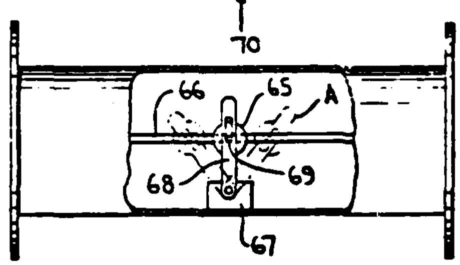


FIG. 9a

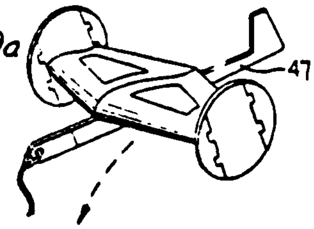


FIG. 9b

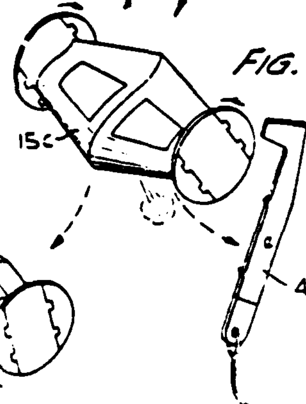


FIG. 9c

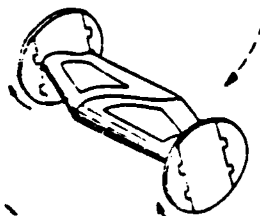
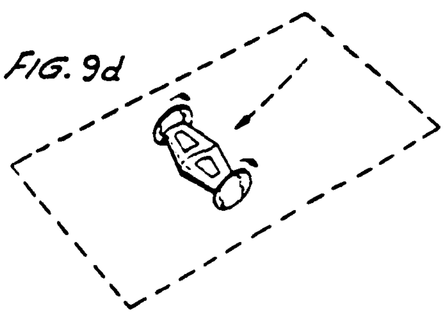


FIG. 9d



INVENTORS.
GABRIEL D. BOEHLER
WILLIAM F. FOSHAG

BY Watson, Cole, Grindle & Watson
ATTORNEYS

FIG. 13

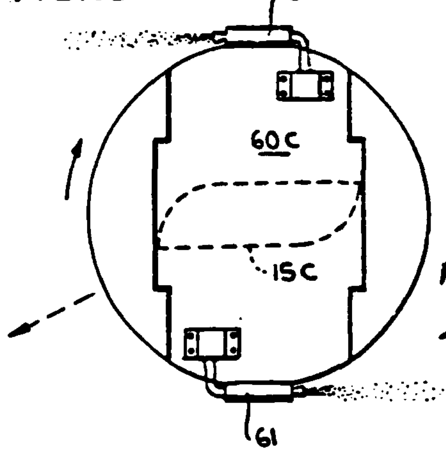


FIG. 16

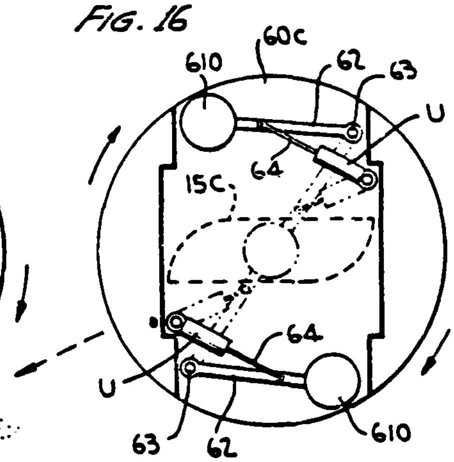


FIG. 17a

FIG. 17b

FIG. 17c

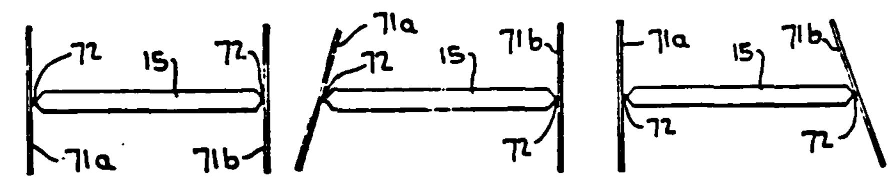
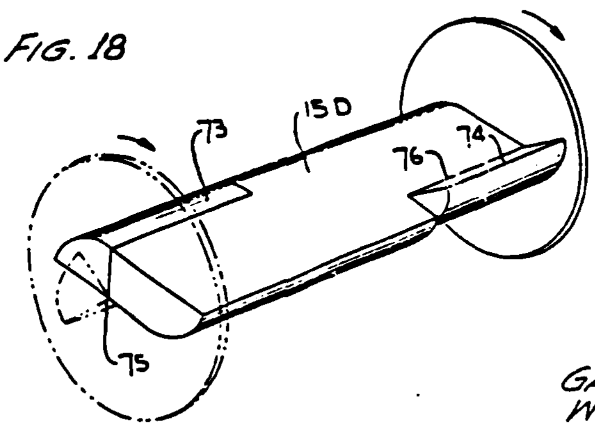


FIG. 18

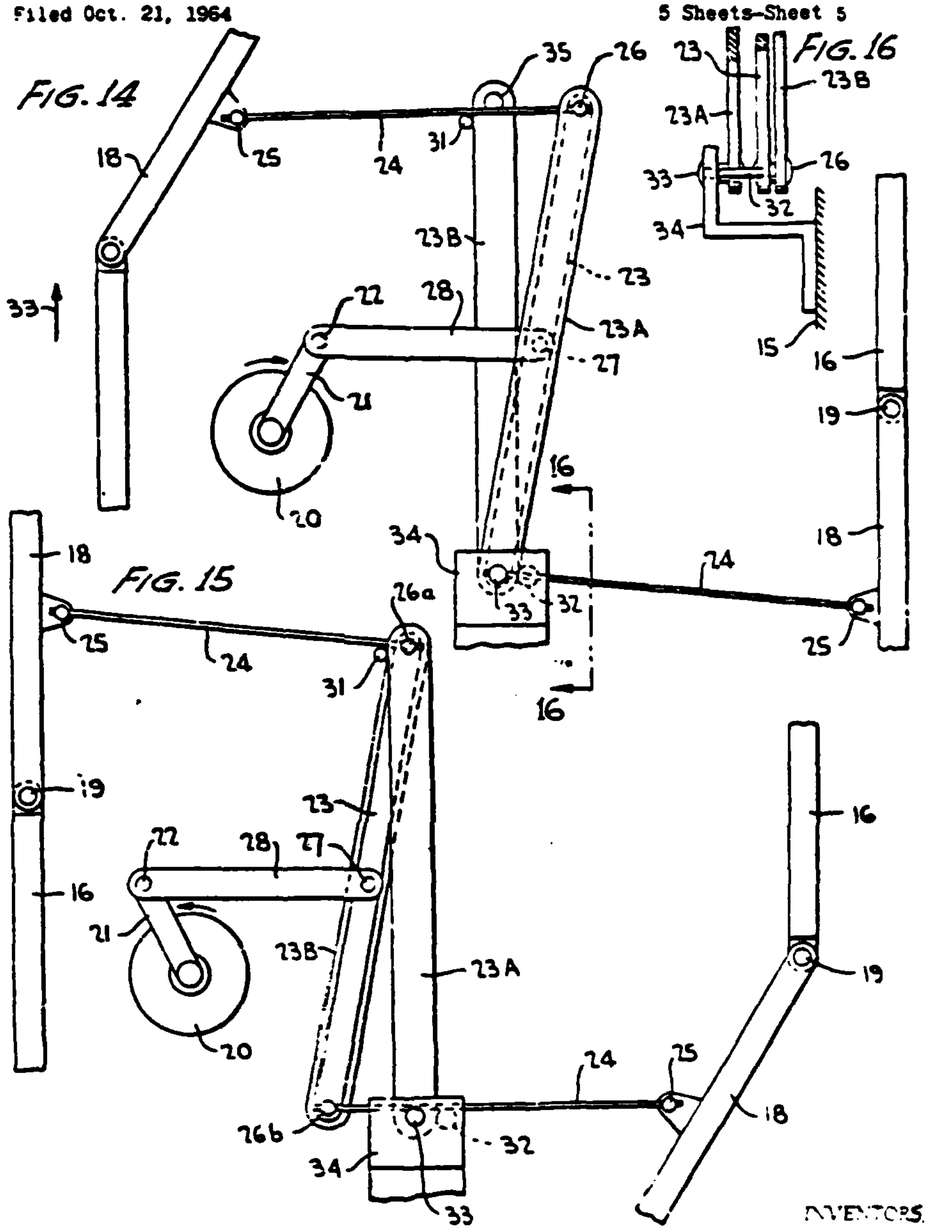


INVENTORS.
GABRIEL D. BOEHLER
WILLIAM F. FOSHAG

BY Watson, Cole, Grindle & Watson
ATTORNEYS

WING ROTORS

Filed Oct. 21, 1964 5 Sheets-Sheet 5



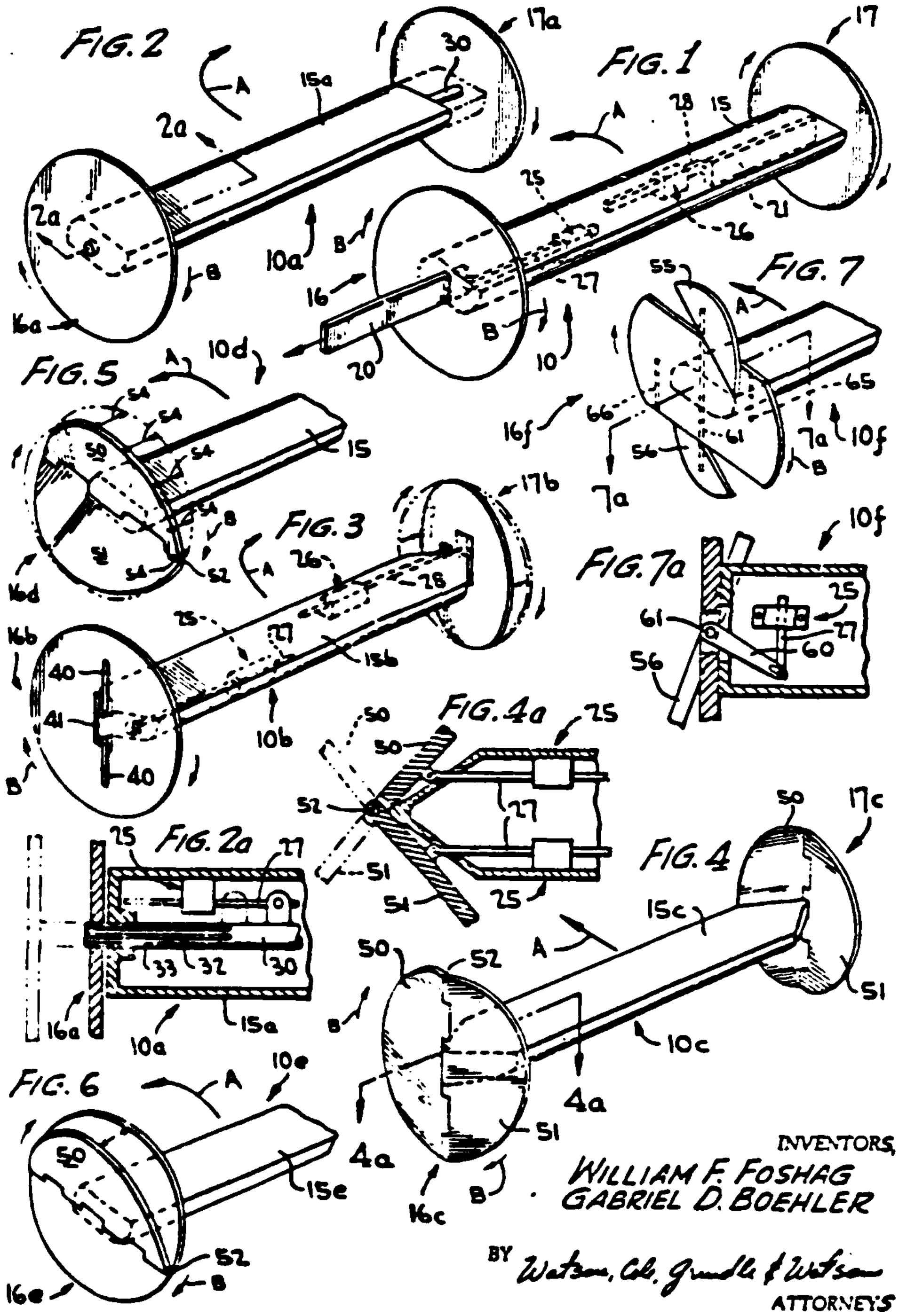
INVENTORS.
GABRIEL D. BOEHLER
WILLIAM F. FOSHAG

BY Watson, Cole, Grindle & Watson
ATTORNEYS

April 22, 1969 G. D. BOEHLER ET AL 3,439,887

WING ROTOR CONTROL APPARATUS

Filed July 22, 1966



INVENTORS,
WILLIAM F. FOSHAG
GABRIEL D. BOEHLER

BY Watson, Cole, Grindle & Watson
ATTORNEYS

S.W. YUAN, WING-TIP VORTICES CONTROL, U.S. PATENT 3,692,259, ISSUED SEPTEMBER 19, 1972

The main body of the Yuan patent deals with the control of vortices by means of various jet arrangements. One embodiment, however, calls for a transverse roller for that purpose. Although not specifically stated in the text, such a roller would cause the Magnus effect because of high pressure air moving spanwise on the underside of the wing. Only the roller modification will be discussed here.

- A form of the invention is disclosed in Figures 8 and 9 wherein a circular cylinder (item 48) is mounted on the wing tip and becomes the very end portion of the wing. The cylinder may be operated by an electric motor or the like in order that it is rotated in the direction that is opposite to the direction of the wing tip vortices. The speed of the rotation of the cylinder can be easily controlled under prescribed conditions. While the cylinder is rotating, the fluid adjacent to the cylinder rotates (because fluid is viscous) simultaneously with the cylinder. This creats a circulatory flow along the (now rotating) wing tip which counter-balances the wing tip vortices and to some extent transforms their energy into lift.

ASSESSMENT: In the case of watercraft, the hydrofoil generates very similar vortices as do the tips of a marine propeller. The device could be used here also to alleviate vortices and thus reduce resistance and thereby increase efficiency.

United States Patent

Yuan

[15] **3,692,259**

[45] **Sept. 19, 1972**

[54] **WING-TIP VORTICES CONTROL**

[72] Inventor: Shao Wen Yuan, 2021 Highboro Way, Falls Church, Virginia 22043

[22] Filed: June 26, 1970

[21] Appl. No.: 50,179

[52] U.S. Cl. 244/40

[51] Int. Cl. B64c 23/06

[58] Field of Search..244/40, 41, 1, 42, 42.41, 17.11, 244/17.13; 115/34; 416/92, 90, 91, 90 A, 20

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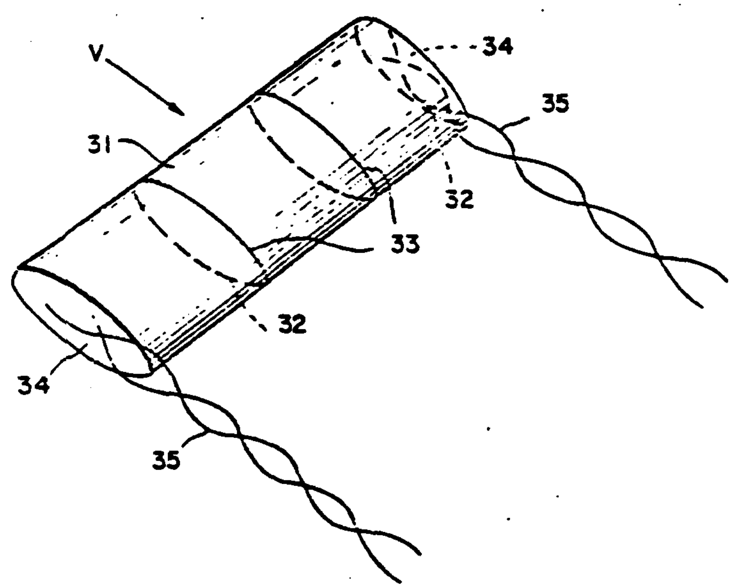
Primary Examiner—Duane A. Reger
Assistant Examiner—Carl A. Rutledge
Attorney—Charles E. Brown, Vincent L. Ramik, William H. Holt, Alfred W. Bruner, John Snyder and Diller, Brown, Ramik & Holt

[57] **ABSTRACT**

This invention is for wings of all types, such as fixed wings for aircraft and hydrofoil boat, and rotary blades (or wings) for helicopters and turbines, to be equipped with a row of chordwise tangential jets along the edge or end surfaces of the wing tips for counter-balancing and controlling the wing-tip or blade-tip vortices.

19 Claims, 13 Drawing Figures



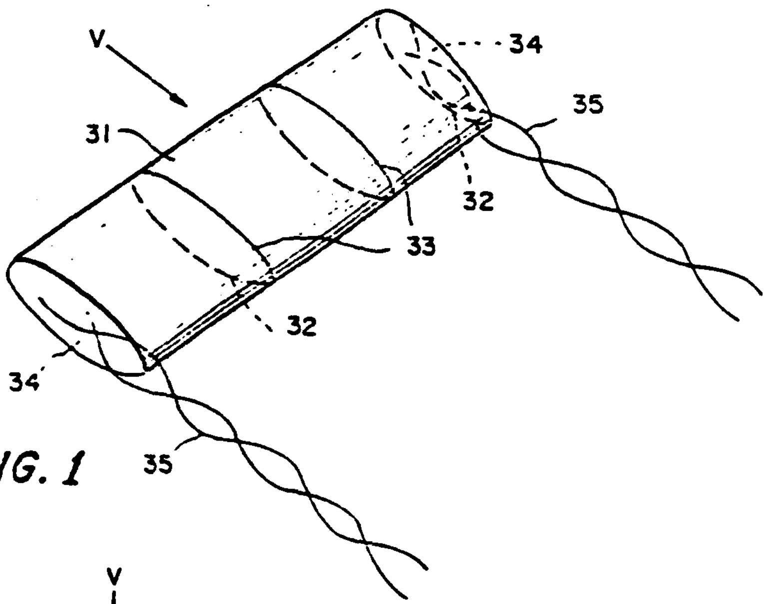


FIG. 1

FIG. 2

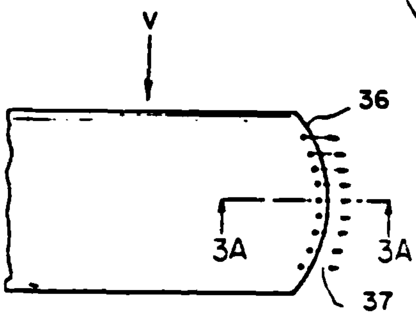
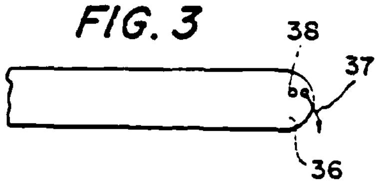


FIG. 3



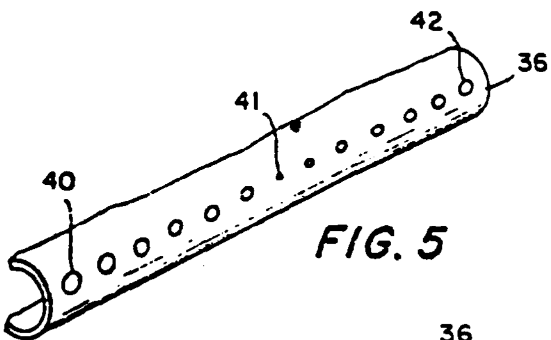
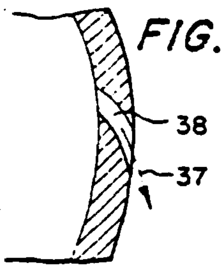


FIG. 5

FIG. 3A



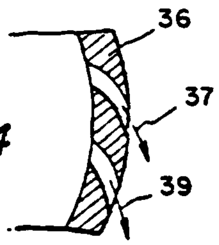


FIG. 4

INVENTOR
SHAO WEN YUAN

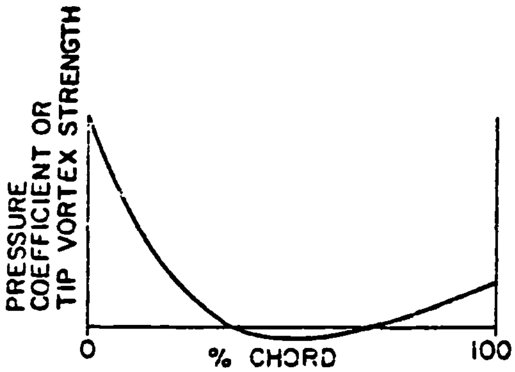


FIG. 6

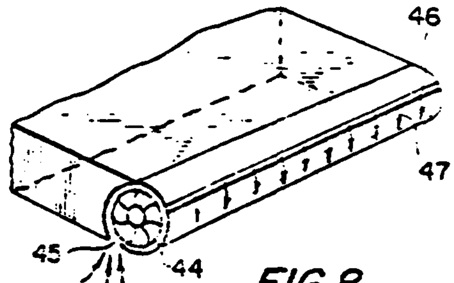


FIG. 8

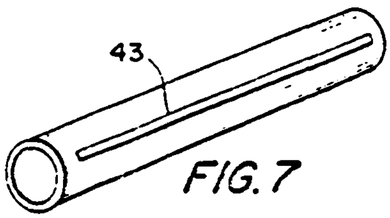


FIG. 7

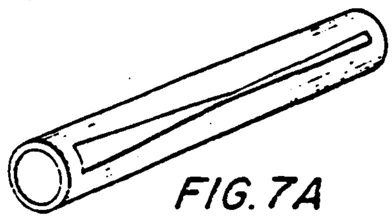


FIG. 7A

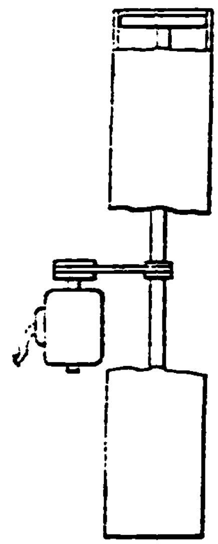


FIG. 8A

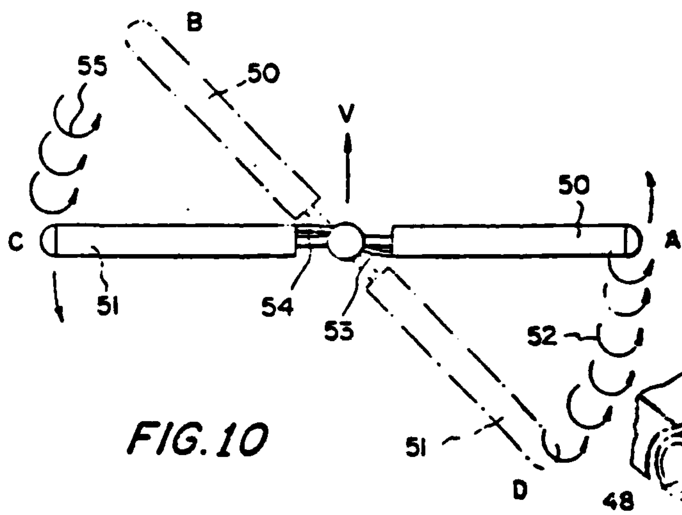


FIG. 10

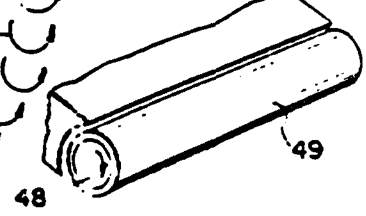


FIG. 9

G.G. HIRS, AERODYNAMIC OR HYDRODYNAMIC ELEMENT, SUCH AS A WING OR A BLADE, U.S. PATENT 3,734,641, ISSUED MAY 22, 1973, ASSIGNED TO NEDERLANDSE ORGANISATIE VOOR TOEGEPAST NATUURWETEN-SCHAPPELIJK ONDERZOEK TEN BEHOVE VAN NIJVERHEID, HANDEL & VERKEER, THE HAGUE, NETHERLANDS

The Hirs patent is an improvement upon the rolling apron invented by Castelcicala (see page 110). In this version, an endless belt runs on a profiled smooth body and is supported by a film of lubricant which is forced through holes under pressure maintaining the belt's rotation.

- Figure 1 and 2 respectively are a perspective view and and a cross sectional view of an element (wing or blade). A fluid lubricant, such as air, is fed to the gap (item 11) through channels (items 7 and 8) via openings, (items 9 and 10). It flows on either side through the gap (item 11) toward discharge openings (items 12 and 13) and at the same time exerts a pressure on the belt (item 3) which comes under stress.

- Figure 3 shows the mutual positions of the openings and grooves of the element. In a way that is known in the art of aerostatic and hydrostatic shaft bearings and similar supports, a balance sets in between the stress in the belt, the local curvature of the belt and the pressure of air on the belt. In order to give motion to the belt, very shallow grooves are provided in it. The depth of these grooves (items 14 and 15) is exaggerated in the drawing.

- Figure 4 shows a variant for those cases in which the ratio of length to circumference is less than great.

- Figure 5 shows still another variant which is not suitable for broad belts.

ASSESSMENT: The Hirs Magnus effect belt system shows great promise for sail propulsion. It has only one moving part, the belt traveling around a light-weight core and driven by compressed air. The element can be streamlined for drag reduction. It is a practical step beyond the original revolving cylinder idea and may lead to a new generation of more sophisticated Magnus effect applications.

United States Patent [19]

Hirs

[11] **3,734,641**

[45] **May 22, 1973**

[54] **AERODYNAMIC OR HYDRODYNAMIC ELEMENT, SUCH AS A WING OR A BLADE**

[75] Inventor: Gilles Gerardus Hirs, Fijnacker, Netherlands

[73] Assignee: Nederlandse Organisatie Voor Toegepast-Natuurweten-Schappelijk Onderzoek Ten Behove Van Nijverheid, Handel & Verkeer, The Hague, Netherlands

[22] Filed: May 28, 1971

[21] Appl. No.: 147,860

[30] Foreign Application Priority Data

May 29, 1970 Netherlands 7007868

[52] U.S. Cl. 416/4

[51] Int. Cl. B63b 9/02

[58] Field of Search 416/4; 415/90; 244/10, 21, 39

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260,839	10/1928	Italy	244/21
112,318	12/1925	Switzerland	244/10

Primary Examiner—Everette A. Powell, Jr.
Attorney—Hammond & Littell

[57] **ABSTRACT**

Wings, blades and such aerodynamic and hydrodynamic elements, which are profiled to experience in a stream of a gas or a liquid a transverse force and which are provided with a moving surface constituted by a rotating belt of flexible material to benefit from the Magnus-effect and thus to increase efficiency, are improved by running the belt on a profiled body instead of on rollers. The belt is supported by a film of lubricant which is supplied through holes and distributed by grooves in the body, in such an arrangement that the lubricant flow not only supports the belt but also maintains its rotation.

6 Claims, 5 Drawing Figures

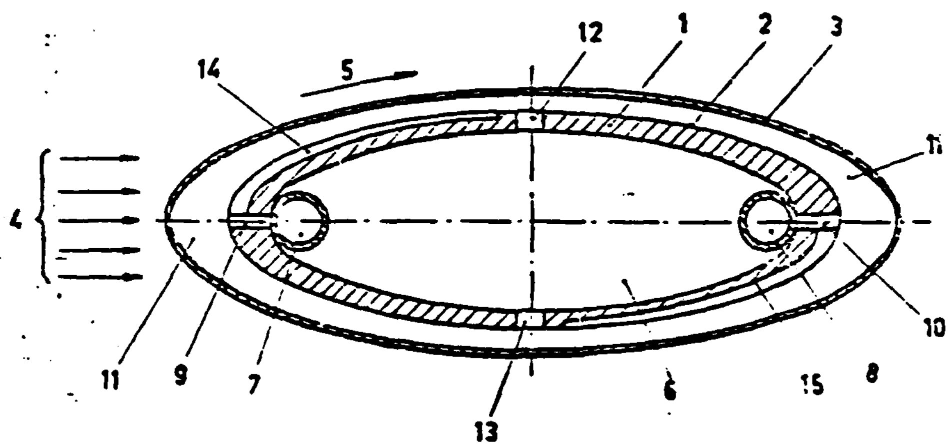


FIG.1

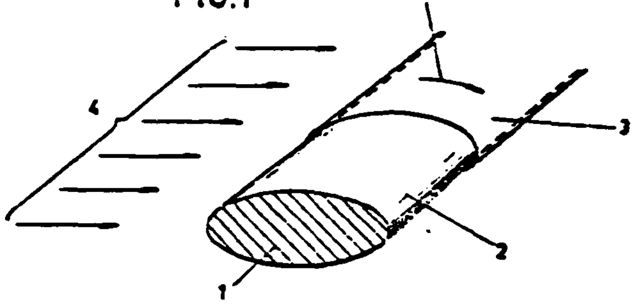


FIG.2

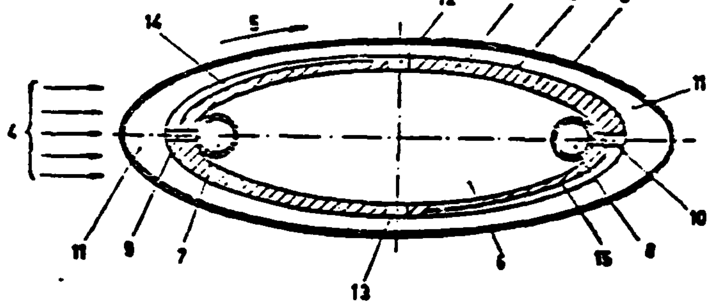
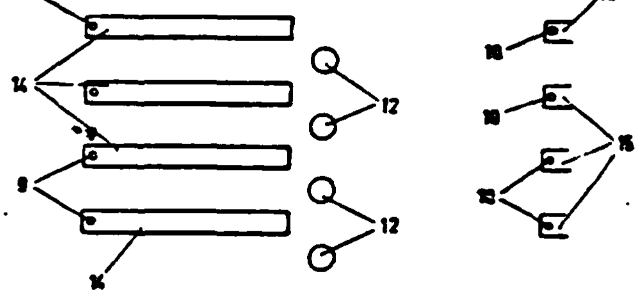


FIG.3



INVENTOR
GILLES GERARDUS HIRS

BY [signature]
ATTORNEYS

FIG.4

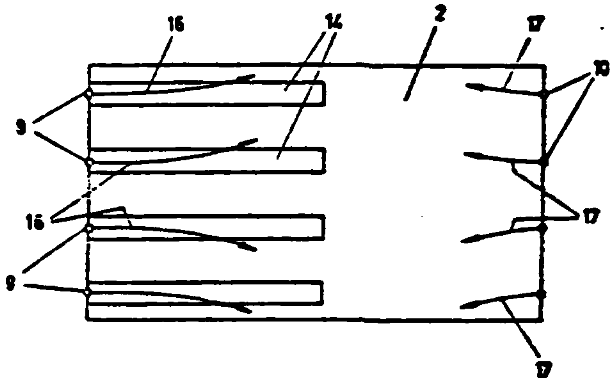
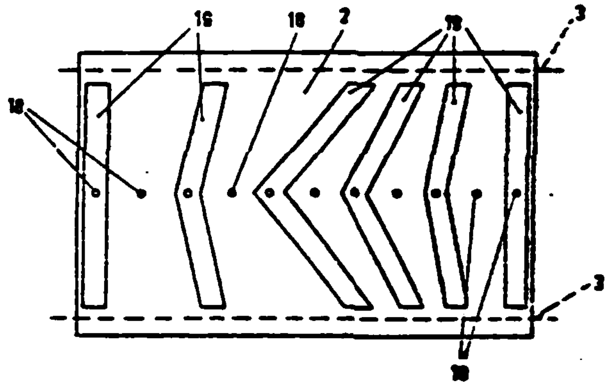


FIG.5



INVENTOR
GILLES GERARDUS HIRS
BY
ATTORNEYS

P.A. SHARP, FREE FLYING AERODYNAMIC TOY WITH HIGH STABILITY, U.S. PATENT 4,051,622, ISSUED OCTOBER 4, 1977

This invention is an autorotating Magnus effect toy glider. The wing section bears a similarity to the Boehler glider (see page 171) except that the wing rotors taper outboard from the center of the span at a dihedral angle so as to produce greater stability.

- Figures 1 and 2 are side and plan views of the toy showing the center rib (item 28) and the end plates (items 30 and 32), The rotor is provided with a visual indicator (item 34) to assist in proper orientation when launching.

- Figure 3 is a sectional view taken along line 3-3 in Figure 2 and showing the rotor section to be wider at the outboard end.

- Figure 4 is a sectional view taken along line 4-4 in Figure 3 showing the center section of the rotor.

- Figure 5 is a cross section of the end plate taken along line 5-5 in Figure 3, a weighted annular disk (item 32) whose inertia helps keep the rotor spinning.

ASSESSMENT: This patent is of little value except to demonstrate how the Magnus effect works.

United States Patent [19]

Sharp

[11] **4,051,622**

[45] **Oct. 4, 1977**

[54] **FREE FLYING AERODYNAMIC TOY WITH HIGH STABILITY**

[76] Inventor: Peter A. Sharp, 520 Utah St., San Francisco, Calif. 94110

[21] Appl. No.: 676,042

[22] Filed: Apr. 12, 1976

[51] Int. Cl.[2] A63H 27/00

[52] U.S. Cl. .... 46/74 R; 46/60; 244/21; 244/153 A

[58] Field of Search .... 244/10, 21, 39, 153 A, 244/153 R; 46/74 R, 75, 82, 85, 84, 60-63, 83; 416/4; 273/95 R, 106 R

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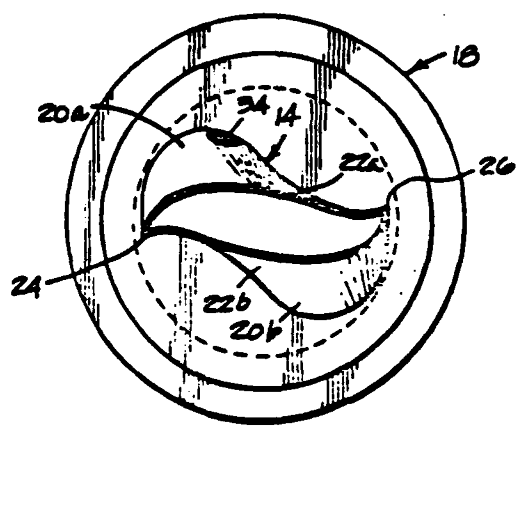
Primary Examiner—Trygve M. Blix
Assistant Examiner—Galen Barefoot
Attorney, Agent, or Firm—Robert Charles Hill

[57] **ABSTRACT**

A free flying aerodynamic toy that is manually launched and is composed of an elongate air foil having two identical surfaces that are joined to one another symmetrically of the longitudinal axis so that in response to rotation and translation through air, the surfaces sequentially cooperate with air flow thereover to produce lift. Circular stabilizer plates at opposite ends of the air foil produce vertical stability and have weighted peripheries to increase rotational inertia. Centrally of the air foil is a rib which divides the air foil into two symmetrical parts. The parts extend outward from the rib at a positive dihedral angle (an included angle less than 180°) so as to enhance stability and reduce roll and yaw of the toy.

4 Claims, 5 Drawing Figures



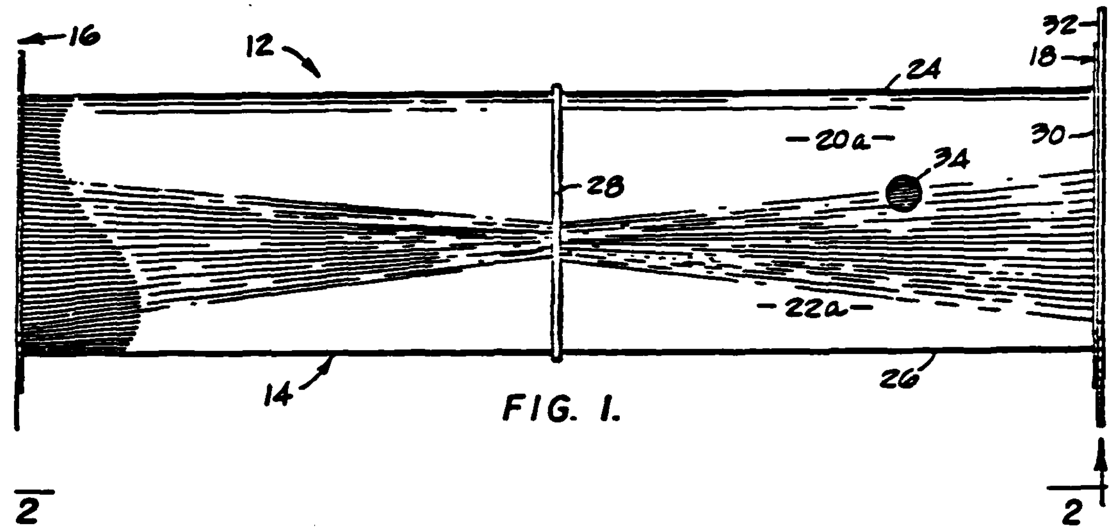


FIG. 1.

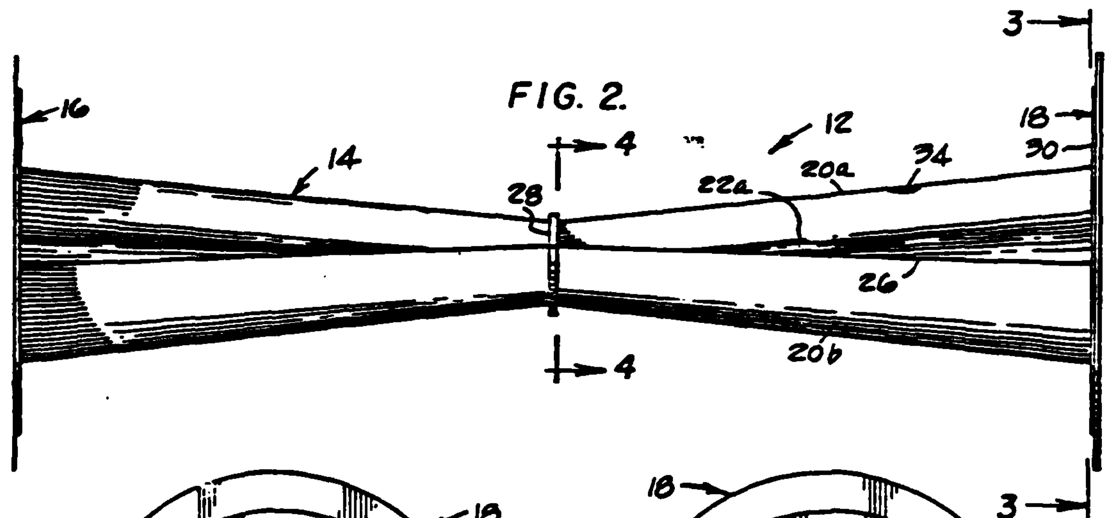


FIG. 2.

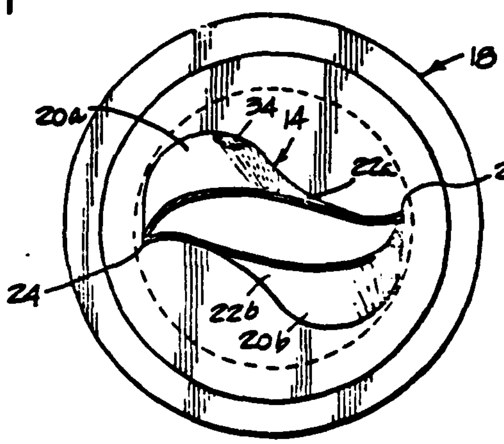


FIG. 4.

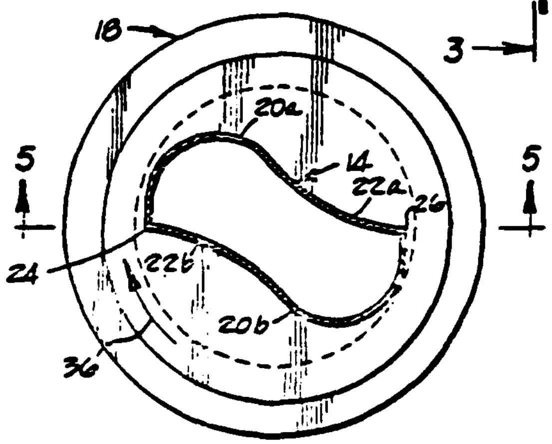


FIG. 3.

FIG. 5.