

SHADOW - A UNIQUE FLYING ENTITY

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SUMMARY

This writing concerns a new generation of miniature, autonomous flying devices. Ken Shoulders established the basic concept over thirty years ago in a series of working prototypes done as a hobby. The vehicle is a disc shaped, ducted fan having highly controllable, contrarotating impellers powered by a specially designed internal combustion engine. The vehicle is outfitted with numerous sensors giving it such a high degree of autonomous flight that intelligence is assigned to it by those watching its performance.

PREAMBLE

No inexpensive flying machine capable of sensible, independent action has yet been produced which has captured the world's imagination and markets. This writing concerns just such an invention. It is a machine that is attracted to people, that is delightfully playful, and has the elements of being capricious. It is capable of agile flight yet still safe to those around it. It can be called upon and directed to do many complicated, lifelike tasks. It can be summoned to play games, or if told to wait at a particular spot, it will do so until its fuel is exhausted. When it is in a crowd of people or objects, it knows who its master is and, like their shadow, will obediently follow them, above their heads and out of reach of others if necessary. When alone, it will come down and be its master's companion.

Generally, fads are rare and thought to be impossible to predict, but given the characteristics available in this class of *entity*, I am predicting one. SHADOW is the kind of device that has the allure of video games, but is based on far more interesting and real physical action. It has all the ingredients needed to start a worldwide fad.



STEVE

TECHNICAL DESCRIPTION

Technically, the machine is a ducted fan class of vertical take-off and landing rotorcraft using vectored thrust for control. The overall appearance, as shown in Fig. 1 and Fig. 2, is that of a flying saucer. The configuration shown is an updated version of an older design with extreme emphasis placed on safety while making the necessary trade-off with efficiency.

A very large percentage of the total thrust is useful for control by employing high-speed, pneumatically powered vane actuators imbedded in the impeller that is housed in the duct. Two of these control vanes, located on the tips of a contrarotating test rig, are shown in Fig. 3 while Fig. 4 shows several earlier test vanes. Each of the rotors or impellers have 12 blades on them. This control method gives SHADOW a 3G maneuvering capability, rendering it almost impossible to catch by an unaided human.

KEN

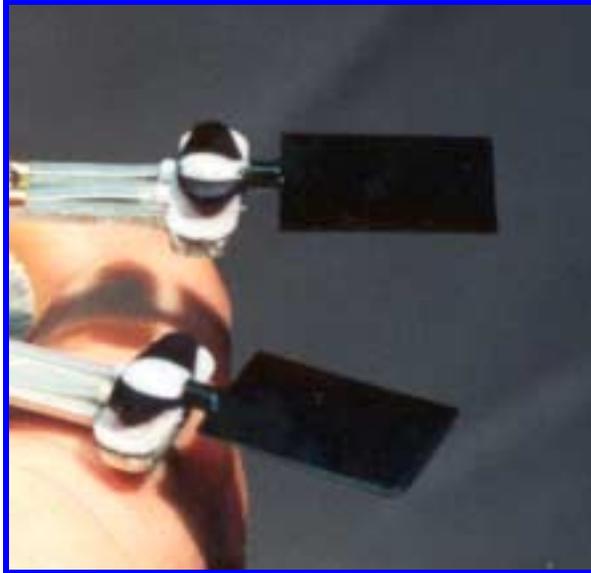


Fig. 3 Pneumatically operated, contrarotating vanes.



Fig. 4 Older versions of impeller vanes.

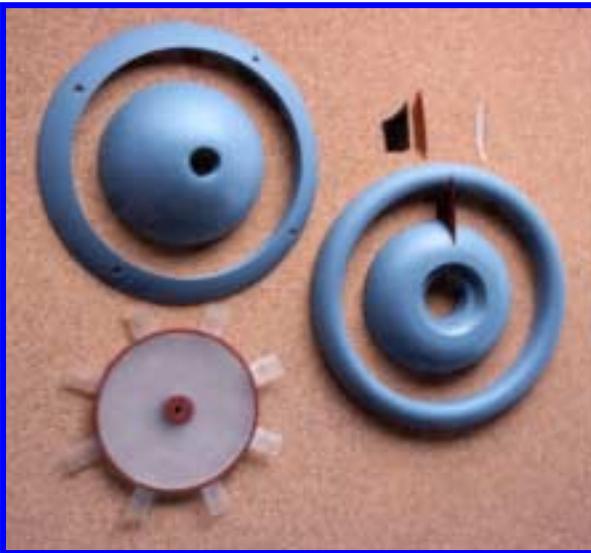


Fig. 5 Internal molded parts of structure



Fig. 6 Top view showing inlet vanes.

Fig. 5 shows the internal molded parts of test structures while Fig. 6 shows a top view of the inlet vanes.

The engine operates as a 2-stroke, sleeve-valve, uniflow scavenged, spark ignition, internal combustion engine fueled by liquid petroleum gas (LPG). This combination greatly facilitates remote starting, lowers the noise and removes odor and oil emissions. A drawing of the engine layout shows in Fig. 7 and a photo of a test unit designed to measure valve timing and lubrication affects along with combustion and cooling properties is shown in Fig. 8.

As shown in Fig. 7, the engine has two cylinders with one of them acting as the power cylinder and the other acting as an air compressor. The air power produced by the compressor both charges the power cylinder and provides pneumatic power for operating the impeller vanes and fuel metering functions. Another feature of this design is that the piston, sleeve valve and cylinder are easily fabricated from ceramic. This construction technique has been tested as rotor air bearings and impeller vane air commutators and found to be very amenable to small engine use. The range of power output over which this design functions well is from 10 watts to 100 watts.

Fig. 7

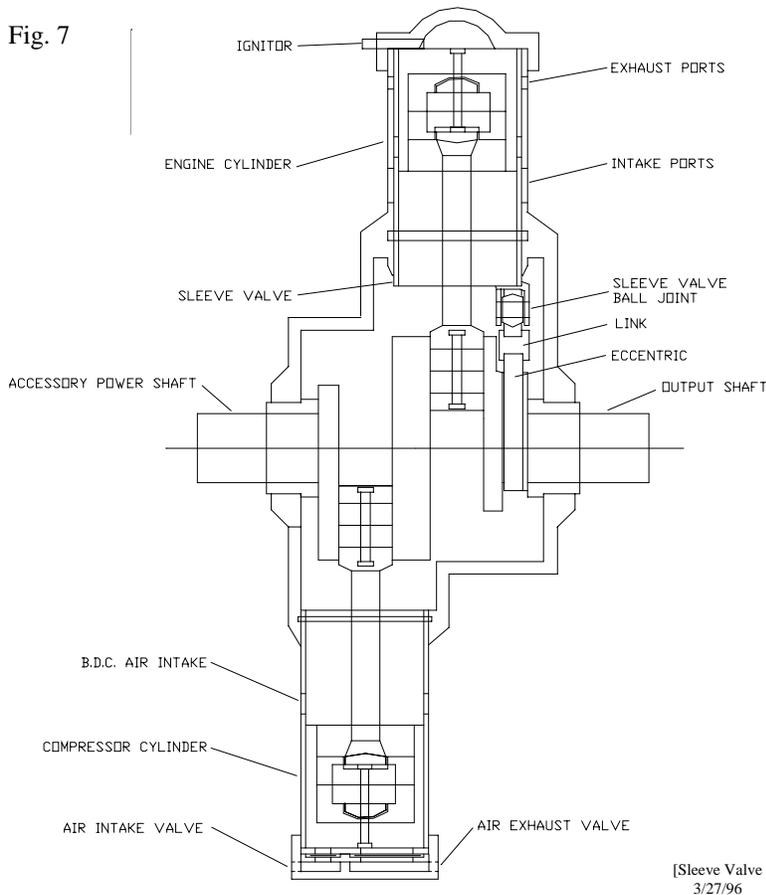
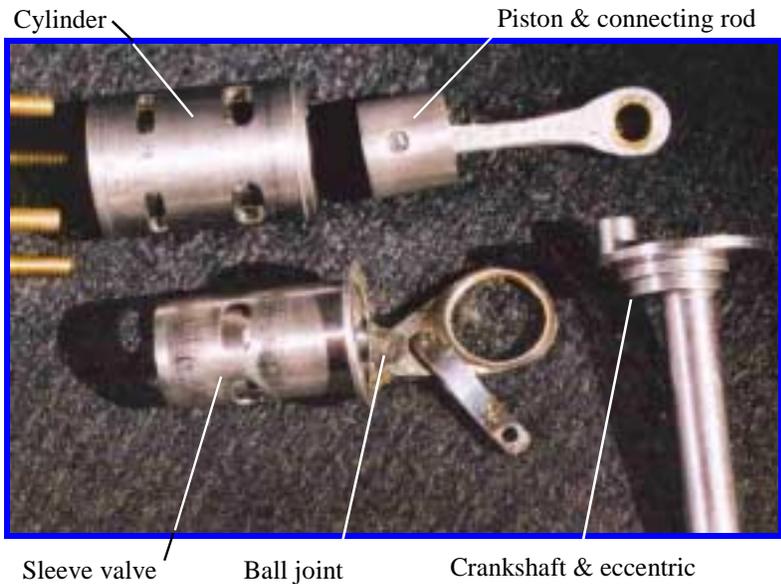


Fig 8 Photo of Experimental Sleeve Valve Engine parts



SHADOW carries with it an ultrasonic sound source and appropriate detectors to regulate the vehicle height and sense nearby obstacles, avoiding them by vectoring the thrust away from the object when it is too close. The vehicle body is stabilized in the plane of flight by a combination of ultrasonic sensing, earth field magnetic detection and airspeed detection. Applying differential torque to the impeller discs controls the heading of the body. When using sonic sensing, there are two competing functions in the control of the vehicle. First, to be attracted to an object from a distance, and then, this function is overridden by a repel function to find an equilibrium distance from the object and to lock there. Both the stand off distance and the height are continuously adjustable functions within limits of about 2 feet at the closest approach to a maximum of 20 feet from the object or ground.

Although no skill is required to operate the vehicle in the most basic modes, either a radio or ultrasonic link can be used to create higher modes of operation. Control distance is typical of low-power radio channels, being several thousand feet for a small hand-operated controller. An automatic homing function prevents the vehicle from getting out of range. The repel and attract channels in the control system are offset tuned from the vehicle ultrasonic source so that Doppler shifts are effective in giving the vehicle more interesting responses. If the repel channel is tuned higher than the sound source frequency, then the objects moving toward the machine are sensed more quickly or at a greater distance and the machine will run from them. On the other hand, the vehicle chases objects that recede rapidly and the stand off distance will be reduced. When the vehicle is required to fly through congested space, such as wooded areas, it strives to maintain the last heading, altitude and speed command. In the event of complications, the vehicle alters the input commands and performs needed maneuvers to continue to the target area. It is functions like these that give it the appearance of being somewhat intelligent.

THE BASIC FUNCTIONS PRODUCED BY THE CONTROL SYSTEM

- Altitude regulation by ultrasonic sensing is used to maintain a prescribed height above any surface or cluster of obstacles. Overhead distance from objects is also averaged.
- An ultrasonic, anti-collision technique is used resulting in the avoidance of obstacles above a certain minimum size.
- Attraction to objects that are near the vehicle horizontal plane is combined with the repulsion characteristics of the anti-collision system to produce a standoff distance that is an automatic, yet controllable parameter of the vehicle.
- Variation of standoff distance depends on the movement of the object relative to the vehicle, being closer for a receding target than for an advancing target.
- Control of vehicle heading and airspeed or ground speed is based on azimuthal air pressure detection and Doppler ultrasonic detection relative to the earth magnetic field vector.
- Gyroscopic damping signals are available arising from spinning impellers.
- Barometric height and rate controls are used when operated out of ultrasonic target range.
- An automatic landing maneuver capability is available that is either under operator control or upon low fuel warning.
- Automatic homing occurs in case of either low fuel or low signal strength from controlling transmitter.
- GPS guidance and positioning is used for basic navigation.
- Doppler sonic navigation and ground speed tracking is used for long-range flights when GPS signal fails.
- Remote engine start and shutdown, as well as an idle condition, is available for landed operations, such as TV viewing, needing electrical power from the alternator.

These basic characteristics, achieved in an integrated system of great physical simplicity, are the subject of U.S. Patent No. 3,915,414, issued to the author in 1975. Using modern electronic technology, the cost burden of achieving very complicated functions in autonomous flight vehicles, operating with variations on the system described, is minimal.

SPECIFICATIONS FOR SHADOW

Diameter	7 in.
Thickness	3 in.
Weight	6 oz.
Engine Type	2 stroke, 0.05 cu. in., through-flow scavenge, fuel injection.
Fuel	LPG
Maximum Flight Duration	40 min.
Maximum Flight Speed	60 mph
Maximum Anti-Collision Distance	40 ft.
Minimum Standoff Distance	2 ft.
Maximum Standoff Distance	20 ft.
Minimum Height Above Ground	2 ft. (Under ultrasonic control)
Maximum Height Above Ground	30 feet (Under ultrasonic control)
Nominal Control Distance	1 mile (Without using an aerial platform relay station)

GAMES: THE POSSIBILITIES

The market potential of this product can be appreciated by examining the world of possibilities it opens up for new games. The games' functions produced are interesting, and the vehicle's response to dynamic situations in which players vie for the attention of SHADOW by their body movements is almost beyond imagination. It is possible to steal SHADOW from another person by executing a complex movement causing SHADOW to follow the fastest moving, nearby target that came from the proper direction and then moved away from the original player in a particular direction. This action is affected by the ultrasonic sensing system without using any external control. When radio control is brought into play, games take on far greater complexity.

The vertical height sensor beam is usually about 90 degrees wide and will not normally interfere with the lateral obstacle sensors, but when an object comes into the beam, the vehicle will rise over it. For example, when SHADOW is hovering 5 feet above the ground, the lateral detection distance for an object to affect the height channel would be about 5 feet also. Small objects like a single player would have less effect on the height of SHADOW than would a group. SHADOW would treat a group of persons arranged around it as if they were the ground and would rise above them.

If a playing field, yard or street were arranged to have goals at any arbitrary spot and the players divided into teams, the aim of one game would be to get SHADOW to follow you into the goal area while the competition would try to prevent it by luring SHADOW to them by either individual or collective action such as shielding SHADOW from capture. Obviously, shielding must not be carried too far or SHADOW will rise up and fly over the captors and reattach to some target outside of the shielding area. A typical flight speed for SHADOW under these conditions would be about 30-40 mph, depending on safety requirements, making capture by physical means very difficult. This type of game can be played without using radio control of the vehicle. Flight duration would normally be about 40 minutes, thus giving ample time for various strategies to develop. Playing could be done either during the day or at night by using alternator power for lights.

If an individual had no one to compete with, he could go out with SHADOW and do a great many novel and fun things. For example, if SHADOW were repelled by the control source toward a wall or other object, such as a hedgerow, it would effectively bounce from the wall by acoustically sensing it and reversing course when the repelling sound source is stopped. The return course would resemble that of a bouncing ball except that it would never physically strike anything. Body control of the vehicle without the use of radio commands would result in an interesting form of handball with the speed of response adjustable at will up to a limit of 60 mph. The remote control could still be used to retrieve 'lost balls' without running after them. If the height channel is coupled to the repel or attract sound frequency, then SHADOW would rise while it was being repelled and sink while it was being attracted, or the reverse, giving interesting three dimensional games for single or multiple players.

A backyard game of aerial croquet can be devised by assigning various obstacles to engage in prescribed ways, involving many skills using such a dynamic, controllable ball as SHADOW represents.

Combat between multiple vehicles is a distinct possibility in which the ultrasonic beams on board the vehicles are used as weapons and can be made to impact on another vehicle sensor in such a way that the target is deactivated when hit appropriately.

For the less energetic players, a simple *electronic dog* walk might suffice, or more simply yet, sitting on the porch and remotely annoying local bugs and other targets of opportunity. It has often been noted in the past that flies and bees are strangely attracted to operating vehicles and the inevitable outcome is for the machine to win, resulting in a messy streak to wipe off the surfaces. For very sedentary players, observing the response of SHADOW to natural disturbances, like the wind, would be pleasant.

SAFETY

The need for safety is paramount. The most striking difference between the early works done by the author on vehicles having independent flight capabilities and the present work is in the degree of safety designed into the machine. There have been large trade-offs made in efficiency to achieve safety while at the same time keeping the

cost and weight low and the flight duration long. No one would mind very much if a friendly, fuzzy little blue globe followed them around to do their bidding, but there is something sinister about an airborne switchblade spinning at high speed. A ducted fan configuration is an acceptable companion from a safety standpoint, but they don't work as well as a switchblade when it comes to the parameters needed for efficient and highly controlled flight. In our present design we have managed to overcome that hurdle to an acceptable degree. In addition, a soft structure is used for most of the parts coming into contact with players and this gives SHADOW no more hazardous features than those found in everyday living.

ANNOYANCE FACTORS

Noisemakers invariably like the noise they make, while other listeners most often object to the noise. Miniature aircraft has acquired a bad reputation for being noisemakers and it would seem to have been done on purpose because it is hard to design them to be noisier. The largest and most easily corrected noise source is the engine exhaust. The second noisiest device is the high-speed propeller. Finally, the mechanical noises radiating from the engine are the least noisy but still remarkably large. In the past we have silenced small engines with lightweight and unobtrusive mufflers so that the noise is barely detectable 30 feet away in a reasonably quiet rural background. In a typical urban area the noise is masked up to a distance of 10 feet.

We have given up on non-shrouded, high-speed propellers for safety and noise reasons and have found the noise from properly shrouded, ducted propellers can be made very low. There is a compromise with good efficiency here, but one that must be made. The engine is totally enclosed in our design and mechanical noise is suppressed by the damping of plastic structures. Noise is largely a function of weight, and efficiency and therefore the horsepower used in a device. SHADOW is thus inherently quieter than a machine designed for lifting heavy loads. In addition, we have plans to incorporate a much quieter type of engine never before used in miniature aircraft.

There is certainly the annoyance of a group of happy people shouting and playing, but we cannot design against that and still achieve our goal of selling SHADOW to everyone that has any vitality at all.

CONVENIENCE

Convenience must be built-in like it never has been before. Almost everyone who has had experience with a model engine knows they can be cantankerous beasts and it is our first goal to dispel the fear that you have to be a specialist to run one. Most engines fail to start because either they have a run-down booster battery, a fuel line plugged with hard to dissolve lubricant residue from evaporated fuel, that hand cranking requires too much skill or that the needle valve adjustment is incorrect.

To offset these problems, it is necessary to begin again with small engine design and essentially make an engine act like an electric motor. To do this we intend to use a uniflow scavenge configuration having only light lubrication in the crankcase instead of mixing with the fuel. We intend to use an easily vaporized fuel like butane-propane to remove temperature sensitivity. The fuel flow will be regulated automatically as an injection through a special injection - ignition plug of our own devise giving engine speed regulation by the control system; thus removing the adjustment problem. The starting cycle is totally controlled by onboard sensors and only needs to be remotely turned on, off or set to idle.

These conveniences are obtained at increased cost, but not greatly so. In the operation of older vehicles, we have consistently used small alternators to supply the electrical power required because batteries are a source of sales resistance and difficulty. The initial cost of the alternator is less than that of rechargeable batteries and quickly adds up to a monetary asset during the life of SHADOW, but most of all, the alternator keeps SHADOW from getting a bad name as a battery user.

MINIMIZING INCONVENIENCE

It is an inconvenience to put fuel in the vehicle but this cannot be avoided. Electric flight would be nice but there is presently no way to do it. We can at least make the process of refueling better by selling fuel cartridges that simply insert in the filler cap without having to open and close various cans or transfer devices.

It is a vast inconvenience to have the oil droplets from a mixed-fuel, 2-stroke engine exhaust pipe sling out on your clothing, the clean walls or windows of the house or on the surface of the swimming pool. By careful design and operation, these droplets can be caught in a section of the exhaust muffler and retained during the flight to be drained later at the end of the flight, but this just does not work for the average user. A separate lubrication in the crankcase has to be used and this can be easily done with the engine design proposed here.

It is also disagreeable to smell the funky exhaust products of a miniature engine. The solution to this is to burn gaseous fuels through a dissociation unit like the one proposed here in the injector - ignitor based on electron cluster technology. This is an area that is very new and presumably very amenable to a strong patent position. If there is any remaining odor at all it can be made pleasant by an additive that causes people to come from miles around to play with you. Perhaps the odors of frying bacon, coffee or orange blossoms, depending on the type of person you want to play with. Such control over exhaust products, give SHADOW distinct indoor flight possibilities.

LOVABILITY

Lovability is designed into the shape and feel of SHADOW, being saucer-like. It is small enough in size to almost put in your pocket, although much of it sticks out. It has a good feel and weight distribution, and effects people like a baseball glove effects players of that game. It has to be made into something that is compact and ever-ready to go with you, even if for just a couple of quick passes at the wall, just as a ball and glove are. We have designs that will come as close to this goal as is economically allowed at this time.

The intrinsic limits of lovability for this class of machine are somewhat beyond where we are now and they are primarily set by the power plant limits. As we go further into the field and can afford the development of small, efficient, lightweight and low cost engines we will be able to package them into neat, compact vehicle designs that will capture the fancy of nearly any thing-lover.

PRICING

Experience shows that quality products can create their own market and command a relatively high price. In the toy field, the customer typically pays 5 times the manufacturing cost, but this average includes the vast majority of products that have low customer evaluation. Fashionable 'designer products' have a much higher price to utility ratio. Manufacturing rates of more than 300,000 units a year would allow a selling price for SHADOW of \$50.00, but in the initial absence of competition it would not be unreasonable to base the price on a value instead of cost and sell the units in the range of \$100.00 to \$200.00.

The sale of fuel is a very attractive market and can be made a captive one using patented connectors, trade names and warnings' signs on SHADOW. Sales will probably be to a market that does not want to experiment and will stick to the manufacturer's recommendations.

MARKET STRUCTURE

Market Segments for SHADOW include a highly competitive age grouping for boys between about 8 to 25 years old. The girl participation factor is an unknown at this time. The group game appeal would be optimized here but still giving good performance with a single player that wanted to practice. Another segment would be older men and women who wanted to keep in shape without going to specially prepared gyms or jogging areas. It would be necessary here to make SHADOW highly maneuverable so that a fast game of single's handball could be played in the back yard without a specially prepared site. Various rules and games would serve to keep things interesting. These machines would need higher reliability and be more expensive than the ones sold for a lower age group.

A segment that is close to the exercise model is the competition class of machine where the appeal of final play-offs between regions demands higher quality and a sales outlet through sporting goods' stores. The machine for creative little people offers another segment whereby the machine can be programmed in advance to do a wide variety of different things. Such card programming techniques add only slightly to the cost. Cross coupling of the various functions would be very instructive, but since the possibility of damaging SHADOW is always there, the participant is up against a real adversary. The price of this device is also somewhat higher than the cheapest toy.

It is obvious that the kit segment of the market is available where the price is lower by a small amount, but the appeal of construction is the main thing sought.

SERVICING

Servicing of such a technical product is necessary, but it should be done in much the same fashion as racecars and other technical products by exchange of sub-assemblies. The cost and time delay of sending SHADOW to service centers are prohibitive to the customer and such stations are very difficult for the manufacturer to establish quickly. The packaged merchandising technique is very good for selling parts and sub-assemblies and is used throughout the model industry.

The main units of SHADOW would be the power unit, impeller wheel and actuators, mainframe, sensors and electronic control unit. The replacement cost of the power unit and mainframe are the highest, and if necessary, they can be broken down into lesser units during design to get comparable costs for all units. The selling price for the total of all the sub-assemblies would be typically 2 to 3 times the price of the completely assembled unit. By using this servicing technique, it is possible to lower the set-up costs of a servicing organization, but it would be necessary to increase the cost of development and possibly to raise the initial cost of the unit, although some manufacturing simplifications result from the modular construction, thus partly offsetting this cost.

PROPAGATING STRUCTURE

The propagating structure that creates the SHADOW market must have at least minimal engineering capability in electronic controls, sonic sensors, aerodynamics and power plants. The product design aspects should be done through several iterations interspersed with customer acceptance tests. Initial manufacturing can be done on a small lot basis either in-house or by assembly of jobbed out parts. Ultimately, high production manufacturing will require either the generation of new plant facilities or the merger with or purchase of an existing company capable of engine manufacture. SHADOW seems to fall in between the hobby and the toy field, but marketing channels for toys would seem to suffice.

THE FUTURE

The future is wide open once a controllable device of this type is successfully introduced. Increased long-range control capability for directing SHADOW to any desired spot within a modest range of a few miles is the next most obvious move. After that, units to perform autonomous, complex functions at great distance are possible. Scaled up versions of the same system would produce TV platforms, messenger machines, industrial pack vehicles and sport devices capable of lifting a man. Further down the line, after the necessary degree of reliability has been attained, personal air transportation can become a reality.