Breaking Up Tornadoes

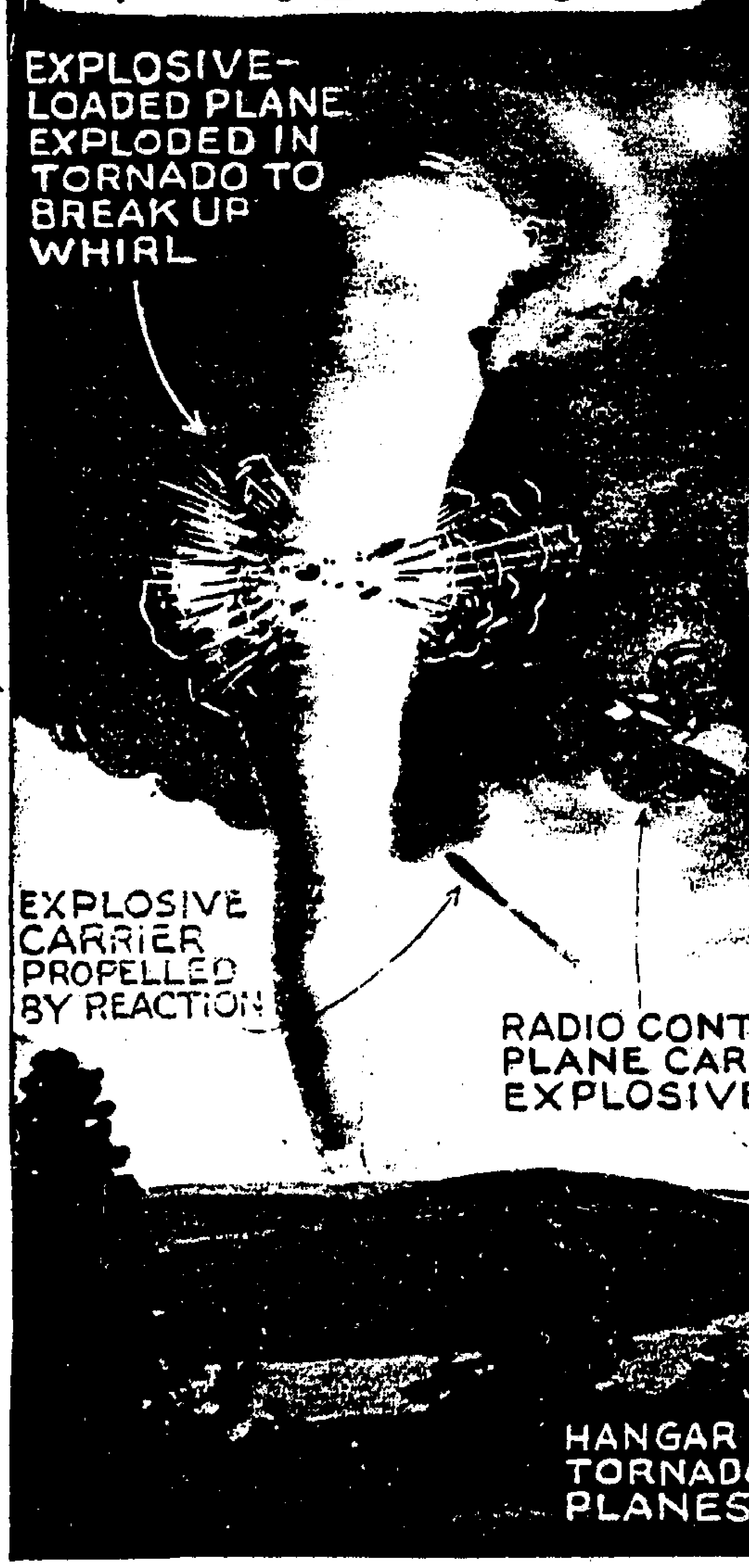
By NIKOLA TESLA

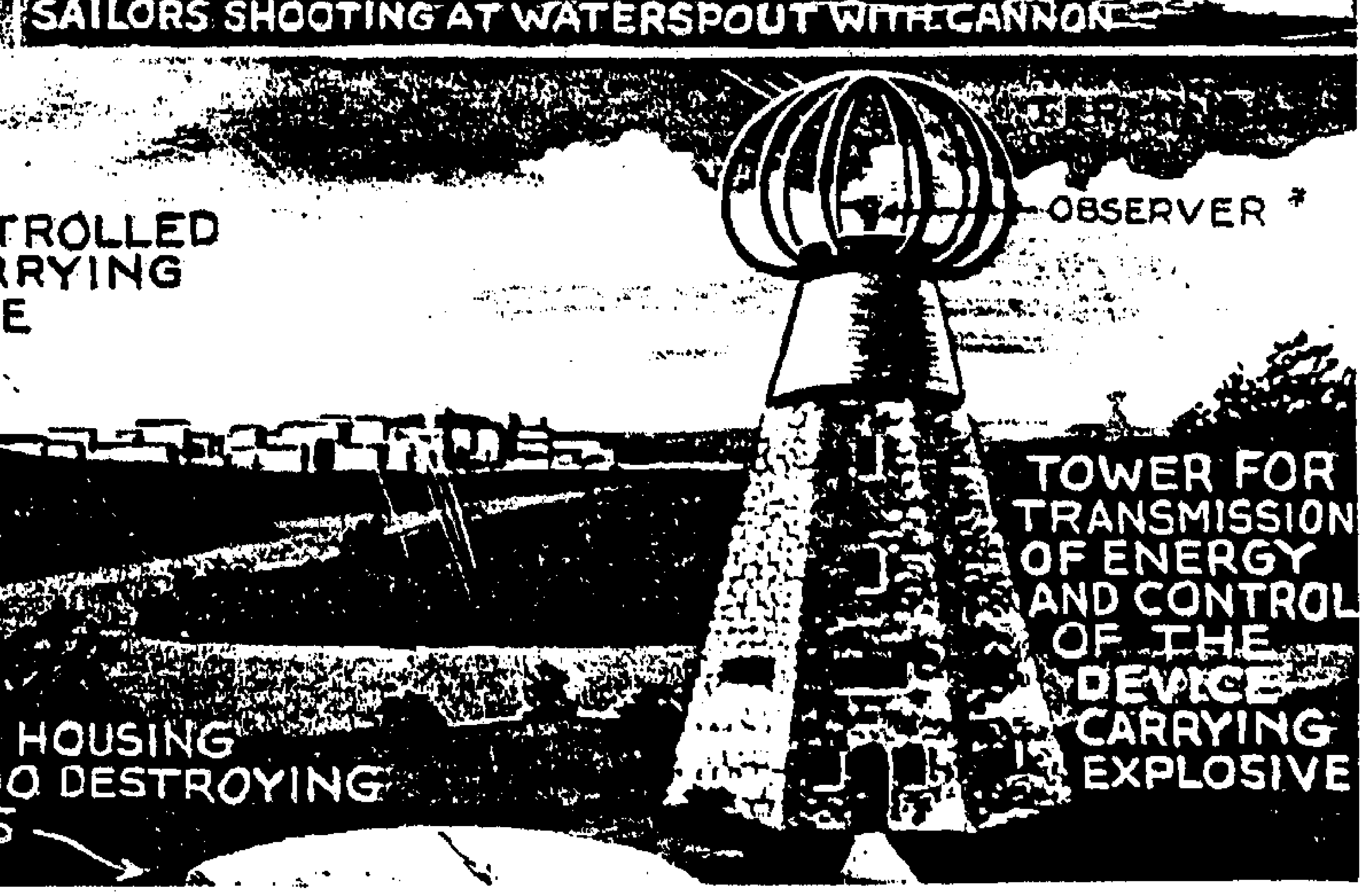
EVERY year whirling tornadoes cause great damage in the United States; and this disaster, like earthquakes, has hitherto been accepted as unavoidable. But the great scientist and inventor, Nikola Tesla, who has given the matter special study, both experimentally and theoretically, here proposes a practicable plan for the organization of a national government service to combat and break up tornadoes, when forming; just as a fire department responds to an alarm and overwhelms the blaze while it is still small. It is to be hoped that this proposal will be met by official investigation and adequate action at Washington.—EDITOR.

● MANY reports of tidal air waves, cyclones, and especially of tornadoes describe actions which are unbelievable; and to account for them some observers have assumed velocities of the order of those attained in explosives.

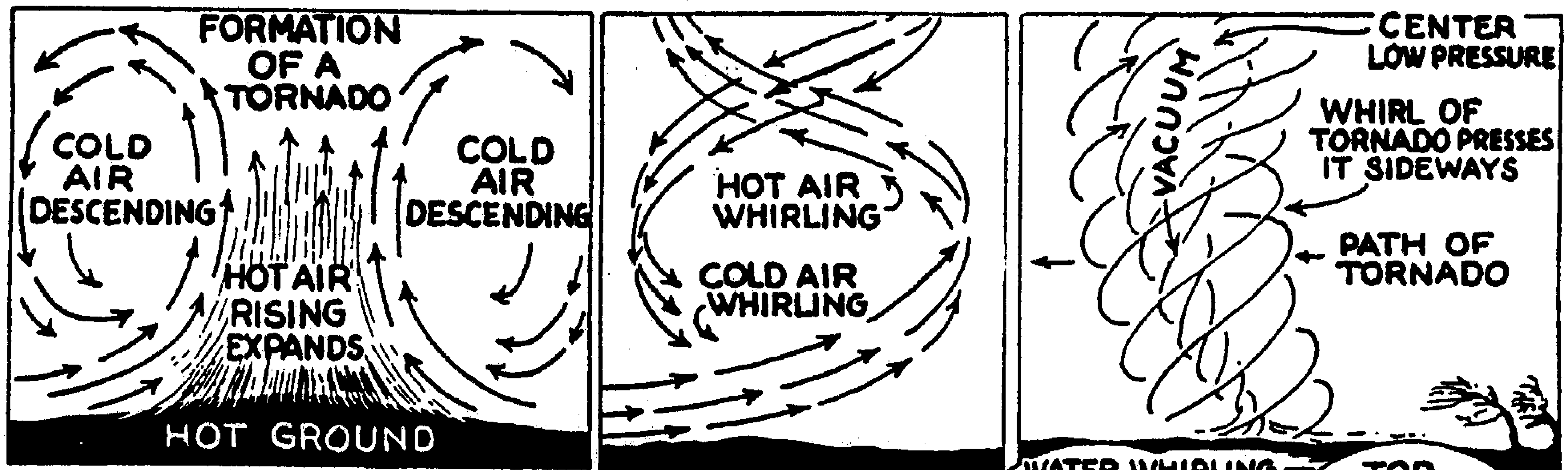
Just to get an idea, suppose that one pound of dynamite occupying the whole volume of its container is ignited. The maximum theoretical velocity *(See Note A at end of article for calculation)* attained in a perfect nozzle is 11,400 feet per second, which is obviously far above that actually attained at the mouth. In such an explosion, however, the gases are projected through a hemispherical opening of great area with correspondingly smaller speed, which is further reduced in accelerating the free air. Thus, at a small distance from the center of the disturbance, the tidal wave advances with the speed of sound; that is, 1089 feet per second.

I have had many opportunities for checking this value by observation of explosions and lightning discharges. An ideal case of this kind presented itself at Colorado Springs in July, 1899, while I was





The old idea of shooting at a waterspout was correct in principle, but insufficient in force. Yet, as calculated here, the force of a tornado can be overcome by modern explosives, which might be efficiently and safely applied as shown.



carrying on tests with my broadcasting power station (which was the only wireless plant in existence at that time). A heavy cloud had gathered over Pike's Peak range, and suddenly lightning struck at a point just ten miles away. I timed the flash instantly and, upon making a quick computation, told my assistants that the tidal wave would arrive in 48½ seconds. With exactly the lapse of this time interval, a terrific blow struck the building, which might have been thrown off the foundations had it not been strongly braced. All the windows on the exposed side and a door were demolished, and much damage was done in the interior. Taking into account the energy of the electric discharge and its duration, as well as that of an explosion, I estimated that the concussion was about equivalent to that which might have been produced by the ignition of twelve tons of dynamite. Though the mechanical effects of lightning bolts diminish with the square of the distance, they are still plainly observable within the range of six hundred miles.

It should be borne in mind that these actions are of very small duration, and that a steady gale of such velocity would produce appalling effects. It would quickly erode and grind up the hardest materials, fuse metals by friction and impact and burn up anything that is combustible. Objects, no matter how large and heavy, would be carried off like feathers, and even a mountain range could not resist for any considerable period of time; since

the pressure on an area normal (perpendicular) to the direction of the air blast would be close to three thousand pounds per square foot. Certainly, the inhabitants of this globe have reasons to congratulate themselves that such storms are impossible. Tornadoes, such as actually occur, are bad enough.

The fact is that relatively very small velocities of the wind are quite capable of producing the actions noted even though they may appear astonishing and puzzling at first thought. To illustrate, consider the mechanical effect of a stalk of dry grass or straw hurled normally against a wooden plank with a speed of only 150 feet per

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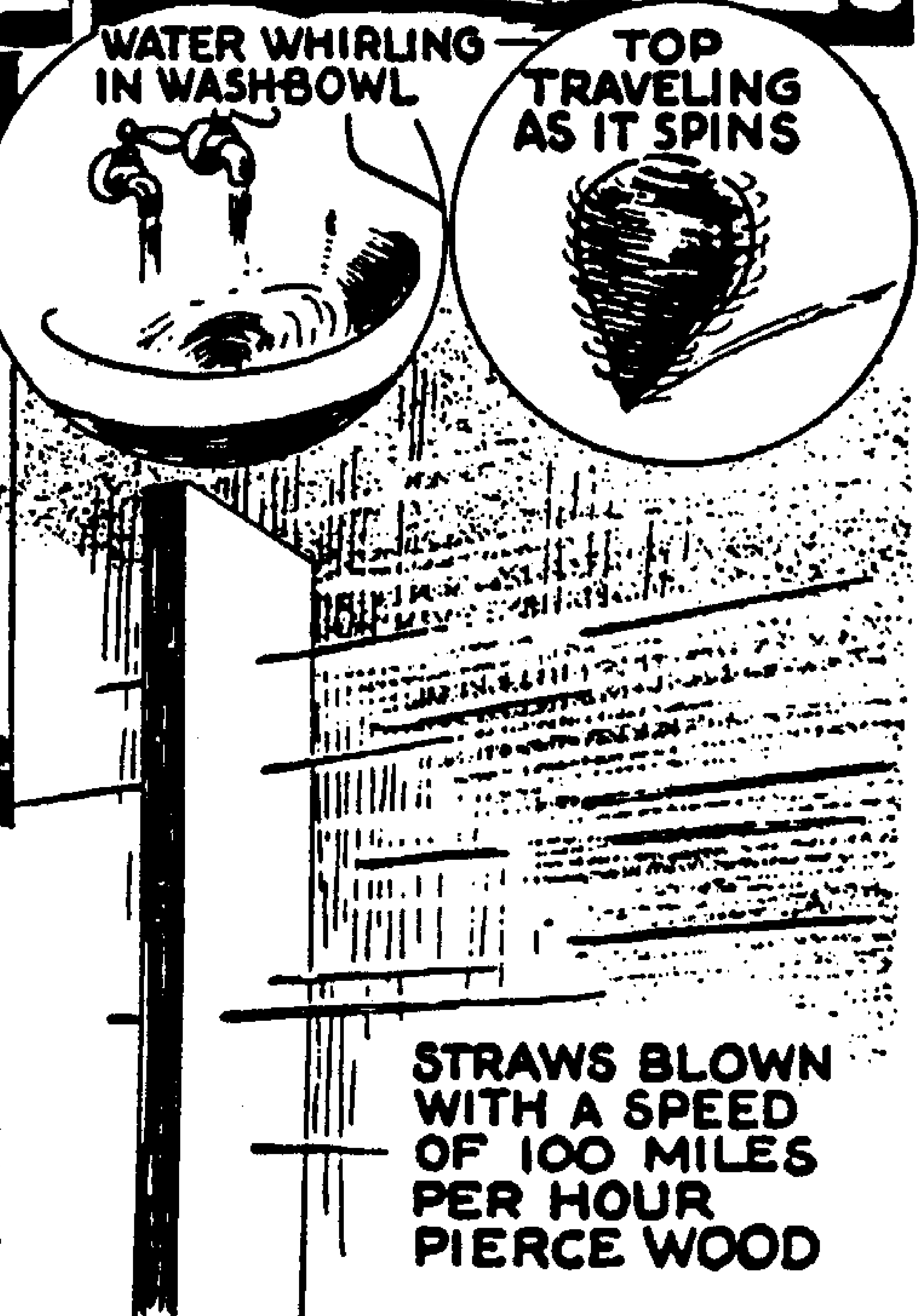

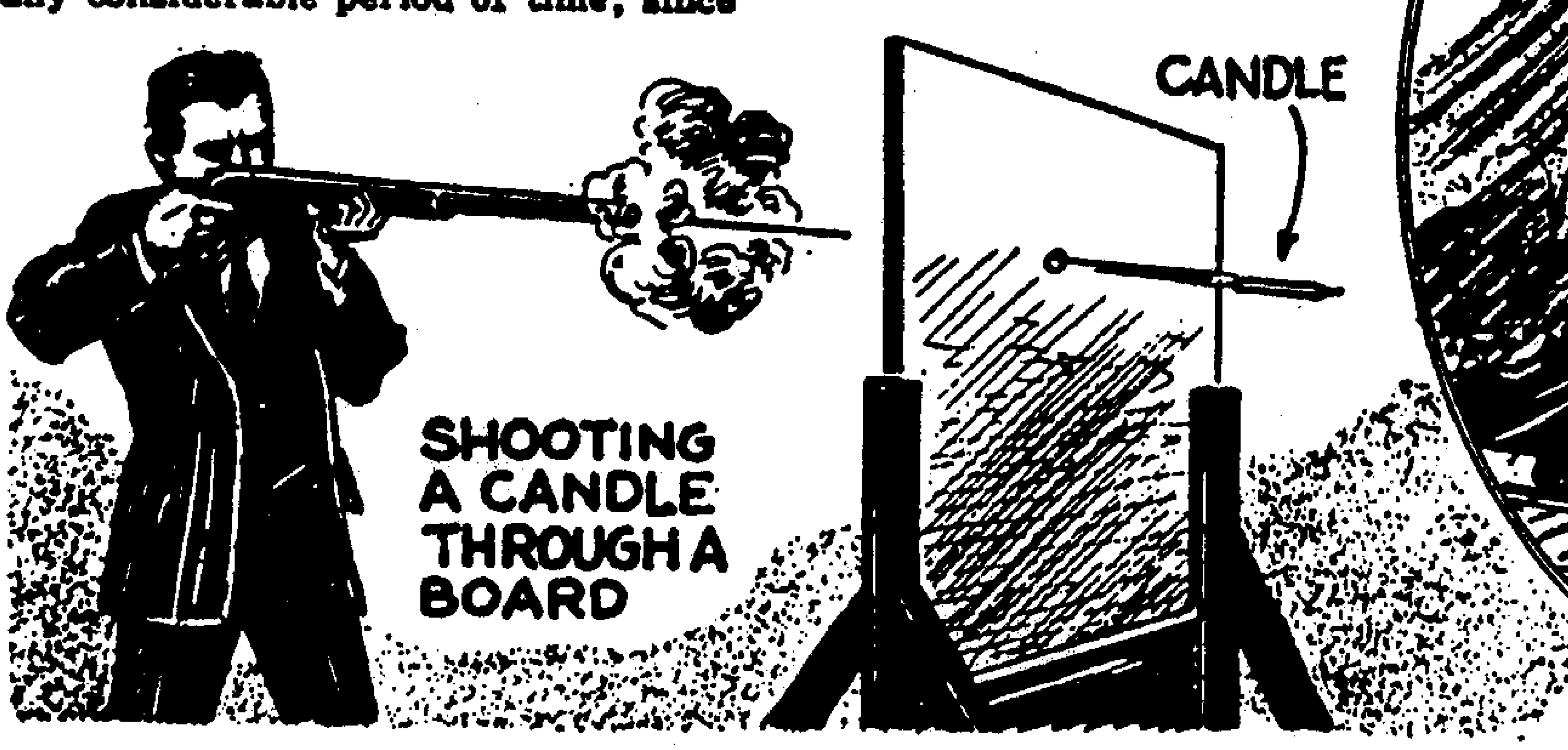

The formation of a tornado is shown above; it spins, as do the waste water and the top. Its tremendous velocity of rotation enables it to accomplish many of the freak results shown; just as when the soft candle is shot undamaged through a hard board.

Breaking Up Tornadoes

(Continued from page 871)

second. (See Note B) The force of 2929.5 pounds per square inch is much more than the plank can withstand; the compressive strength of oak perpendicular to the grain being less than half of that. Evidently, then, an effect of this kind can be surely expected even with much smaller speed, especially if the stalk is pointed.

In this connection it is of interest to mention a classical experiment, which used to be shown to students in some European institutions of learning. It consisted in firing from a gun a tallow or stearin candle at a board 0.4-inch thick. To the amazement of the onlookers, the soft missile not only went through the wood but did not appear much worse for the experience. The secret of success was in the quickness of the transit, not giving enough time for the mass of the candle to yield. The obvious inference from such action is that an exposure to a windstorm is always fraught with danger to life; for bits of flying material, not excluding pieces of straw, may penetrate deeply into the flesh. If my memory serves me right, I have read of serious accidents of this sort.

But the highest air velocities observed in storms are not, in themselves, adequate to explain certain stupendous performances of the wind, such as lifting loaded cars and locomotives and hurling them to great distance. When I first read such reports, many years ago, they afforded me amusement as I took them for original American canards, often sprung on unsophisticated foreigners. When I found, to my unspeakable astonishment, that they were substantially true I endeavored again and again to prove them by theories and calculations; but it was only lately that I solved this long-standing riddle.

Whirling movements of the atmosphere have been known and dreaded since time immemorial, but, beyond accounts of their destructive actions, mostly uncertain, little positive information can be found about them. In 1862 was published by H. W. Dove an important work, entitled "The Law of Storms"; dealing chiefly with cyclones, which frequently extend over a large portion of the globe and travel thousands of miles before their energy is spent. These are easily studied and the chief facts concerning them are now well known. Not so the incomparably more dangerous local storms, the real tornadoes, which are sudden, erratic, ephemeral (short-lived) and extremely violent manifestations difficult to investigate.

Of late years the U. S. Weather Bureau and the Smithsonian Institution have been supplying data which are reliable and of value in connection with the subject; nevertheless, our knowledge of tornadoes is still fragmentary. Ignoring newspaper reports, which are not quite reliable, and confining myself to facts unmistakably established, I have come to certain conclusions regarding these phenomena, which might be important, and can be summarized as follows:

(1) The maximum velocity of the air forming the funnel probably never exceeds, say, 235 feet per second or about 160 miles an hour; which I think ample to explain all the actions observed. In his "Manual of Meteorology," an exhaustive treatise lately published, Sir William Napier Shaw makes the state-

(Continued on page 920)

Breaking Up Tornadoes

(Continued from page 905)

ment that speeds of 300 miles per hou or 440 feet per second, and even more may be attained, which is most unlikel to be the case. It must be borne in min that an air blast of 150 feet per secon readily carries off bricks and other such heavy objects.

(2) Contrary to popular notion, attributing to the tornado immense energy, it has much of the peculiarity of a explosive. Its power is great because o concentration and swiftness of action but the energy is surprisingly small Just to give a rough approximation, consider a whirl of an outside diameter o 1200 feet at the top, about the same height, and a diameter of 300 feet a the base (See Note C). The same energy would be developed by the consumption of 1.24 tons of gasolene o 5.74 tons of dynamite. It should be stated, however, that this estimate is by far too high; for the whole funnel is no filled with air of uniform density and not all of it spun at maximum speed.

(3) The tornado whirl is a huge pump, drawing air through the opening at the top and discharging it from the periphery (rim) at the same rate, simultaneously producing rarefaction in the interior. In this respect its action may be likened to that of a multi-staged vacuum pump; for, as the air rushes from the top to the base, more and more of it is drawn to the periphery, increasing progressively the vacuum which may thus attain a high value near the ground. That accounts for the gradual contraction of the whirl. What degree of rarefaction is actually reached in this monstrous contrivance of nature may be roughly estimated when considering that, for any horizontal section of the funnel, the centrifugal force of the air is balanced by the oppositely-directed differential pressure existing between the outside and interior of the whirl. Other things being alike, the centrifugal force is inversely as the radius of gyration (average distance of the mass from the center); therefore the contraction of the funnel is, at least, a coarse measure of the rarefaction.

To be explicit, if the diameter close to the ground is one quarter of that near the top, then it may be safely inferred that the vacuum at the base must be about four times higher than in the top region, where there is no appreciable contraction.

As the measured pressure difference in pumps is somewhat greater than that given by the formula (Note D) it is tolerably certain that in the case considered a vacuum of not less than four inches would be attained.

(4) Most of the mechanical effects of a tornado are, as a rule, greatly intensified through water, dust, sand and other objects carried by the blast. Even though these materials may be present in a very small percentage by volume, they are hundreds or thousands of times heavier than the air, and may add enormously to the momentum and impact.

(5) The translatory (from place to place) motion of the funnel is rather across, and not in the direction of the wind, as commonly believed. This is due to its rapid rotation, causing the so-called Bernouilli or Magnus effect, only much more intense. The force pushing it across the wind may be many times greater than that urging it along the same. The whirl is propelled from the side of greater static pressure, where the rotation is against the wind and to-

wards which it leans, in the direction of the opposite side where the reverse condition exists. It is well to remember this in such a storm. If the observer sees a leaning funnel, he is in no immediate danger, but if the funnel appears straight he should run for shelter at once.

It will now be easy to show how a large and very heavy body, such as a loaded railroad car or locomotive, can be lifted by the tornado and transported to considerable distance. American locomotives, which are the biggest in the world, may have a length of 66 and a width of 11½ feet, presenting thus 760 square feet in horizontal projection. At the moment the whirl strikes the vehicle, the wheels, connections and other obstacles under the main body arrest the motion of the air, causing a static pressure of 138 pounds per square foot in excess of that of the atmosphere. But as determined above, owing to the vacuum, a pressure difference of four inches of mercury (that is, two pounds per square inch or 288 pounds per square foot) is maintained, making the whole difference of pressure between the spaces under and above the locomotive $288+138=426$ pounds per square foot. The total upward push exerted on the exposed area of 760 square feet is thus 323,760 pounds, which is much more than the weight of such a locomotive (estimated at 280,000 pounds when fully equipped for service).

Ordinarily, the weight should be much smaller; and one can readily see that the vehicle may be instantly raised in a spiral, accelerated and hurled away tangentially to great distance. The average person may be surprised that an insignificant vacuum is sufficient for so stupendous a display of force; but the figures afford an unmistakable proof. I may add that I have assumed minimum values which will be, in all probability, greatly exceeded.

The constant fear of danger from tornadoes and the great losses of life and property which they cause in certain parts make it very desirable to find some means of effectively combating, if not preventing them. Whenever man attempts to interfere with the order of things determined by immutable laws, he finds that his efforts are utterly insignificant when compared with the vast movements of energy in Nature.

One of the greatest possible achievements of the human race would be the control of the precipitation of rain. The sun raises the waters of the ocean and winds carry them to distant regions, where they remain in a state of delicate suspension until a relatively feeble impulse causes them to fall to earth. The terrestrial mechanism operates much like an apparatus releasing great energy through a trigger or priming cap.

If man could perform this relatively trifling work, he could direct the life-giving stream of water wherever he pleased, create lakes and rivers and transform the arid regions of the globe. Many means have been proposed to this end, but only one is operative. It is lightning, but of a certain kind.

More than 35 years ago, I undertook the production of these phenomena and, in 1899, I actually succeeded, using a generator of 2,000 horsepower, in obtaining discharges of 18,000,000 volts carrying currents of 1,200 amperes, which were of such power as to be audible at a distance of 13 miles. I also learned how to produce just such lightnings as occur in Nature, and mastered all the technical difficulties in this connection. But I found that even the small manifestations are of comparatively small energy. It is entirely within our power to destroy them, or at least render them harmless; and all the more easily, since meteorology is becoming a positive science and weather forecasting reliable.

A service with standard bombing planes or swifter types might be organized for this purpose by the Government, for the necessity is real. The tornado, owing to its small energy, extreme mobility and delicate balance between the external and internal pressure, is a very vulnerable object and can be undoubtedly destroyed by comparatively small charges of suitable explosive. The whirling mass can also be easily deflected in any desired direction by exploding a charge even at a considerable distance from it. The task would be further facilitated by the relatively small translatory velocity of the tornado, especially in view of the present means for instant signalling.

I believe, however, that telautomatic devices offer effective means for combating tornadoes. Since I exhibited the first apparatus of this kind, John Hays Hammond, Jr., who has acquired a great mastery of the art, made demonstrations on a large scale, showing the practicability of distant control of complex machinery. It would not be difficult to provide special automata for this purpose, carrying explosive charges, liquid air or other gas, which could be put into action, automatically or otherwise, and which would create a sudden pressure or suction, breaking up the whirl. The missiles themselves might be made of material capable of spontaneous ignition. Many experts are now available for such service and manufacturers can be found competent to carry out any plans.

A Government department might be organized, headed by such a man as John Hays Hammond, Jr., and a systematic study of the problem made. The carrying out of the scheme would give new opportunities for manufacture and employment, besides securing other advantages. There is no doubt that, if such an undertaking were inaugurated and many minds set to work, effective methods and means would be eventually developed and great loss of life and damage to property prevented.

NOTE A: Taking the heating value of the compound as 4100 B.T.U., a constant pressure of twelve thousand atmospheres should be attained; the theoretical temperature of the combustion products being about 8000° F. The highest possible speed would be reached if the gases were to escape into the atmosphere through a perfect divergent nozzle. In this case, the initial absolute temperature would be $T_1 = 8460$ F.; hence the absolute temperature of the fully-expanded gases $T_2 = \frac{8460}{12000^{0.285}} = 583°$ F. Accordingly, assuming the specific heat at constant volume $C_v = 0.33$, the available energy is $W = 7877 \times 0.33 = 2600$ B.T.U., and the maximum theoretical velocity $V = \sqrt{64.4 \times 778 \times 2600} = 11400$ feet per second.

NOTE B: Let the stalk be one foot long, one-eighth of an inch in diameter and of a specific gravity of 0.4 as compared with that of water. The section is then about $\frac{1}{80}$ of a square inch or $\frac{1}{144 \times 80} = \frac{1}{11520}$ of a square foot and, consequently, the volume $\frac{1}{11520}$ of one cubic foot. Since one cubic foot of water weighs 62.45 pounds, the weight of an equal volume of straw will be $0.4 \times 62.45 = 25$ pounds, hence the weight of the piece of straw $\frac{25}{11520}$ pounds and its mass $M = \frac{25}{32 \times 11520}$. Then the kinetic energy is

$$\frac{1}{2} M V^2 = \frac{25 \times 22500}{64 \times 11520} \text{ foot pounds}$$

and will be exhausted in overcoming a resisting force r which the stalk encounters while piercing the wood. If the distance of penetration is 1/2 inch or 1/24 of a foot, then the equation will hold true

$$\frac{22500 \times 25}{64 \times 11520} = r \times \frac{1}{24}$$

from which follows

$$r = \frac{24 \times 22500 \times 25}{64 \times 11520} = 18.31 \text{ pounds}$$

This is the mean value of the force or pressure produced, its maximum being

$$2 \times 18.31 = 36.62 \text{ pounds}$$

As this pressure is exerted on an area of $\frac{1}{80}$ of a square inch, the force per square inch will be

$$F = 36.62 \times 80 = 2929.5 \text{ pounds}$$

NOTE C: The volume is $0.2618\, H\, (D^2 + d^2 + d\, D) = 0.2618 \times 1200\, (1200^2 + 300^2 + 1200 \times 300) = 0.2618 \times 1200\, (1200^2 + 300^2 + 1200 \times 300) = 593760000$ cubic feet, the weight about $593760000 \times \frac{8}{100} = 47500000$ and the mass $M = \frac{47500000}{32} = 1484400$ pounds. If all of it would rotate at the top speed $V = 235$ feet per second, the kinetic energy would be $\frac{1}{2} M V^2 = 742200 \times 55225 = 40988000000$ foot pounds, equivalent to $\frac{40988000000}{778} = 52700000$ B.T.U.

NOTE D: When a mass of air is rotated in a casing with inlet and outlet openings, by a system of discs or other means, the peripheral velocity being V feet per second, a pressure difference of approximately $\frac{V^2}{2g} w = \frac{V^2 \times 0.08}{64} = \frac{V^2}{800}$ pounds per square foot is produced between the suction and discharge orifices. If $V = 235$ feet per second, then $\frac{V^2}{800} = \frac{55225}{800} = 69$ pounds per square foot, or $\frac{69}{144} = 0.48$ pounds per square inch; corresponding to a vacuum of a little less than one inch.

New Devices

(Continued from page 877)

The last item is another household utility which takes into consideration the fact that all have not electric power. It is a standard washer type, equipped by its maker with a small four-cylinder gas engine, which is started by a foot-pedal. A friction-drive pump will empty the tub in less than two minutes. It holds ten gallons of water, and washes six pounds of clothes at one time.