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Mr. Pendray, formerly science editor of the Literary Digest *and now a Westinghouse executive, was one of the organizers of the American Rocket Society.*

PASSENGER FLIGHTS BY ROCKET?

G. EDWARD PENDRAY

NO HUMAN being up to this writing has ever been a passenger in a true rocket, though numerous animals from mice to roosters have been shot by rocket and returned none the worse for it. Some years ago, in 1933, a story came out of Germany that a man-carrying rocket had transported to the considerable altitude of six miles one Otto Fischer of Barmbeck, near Hamburg, but no authentic account of the experiment was ever published. The whole matter was undoubtedly a hoax—possibly based on some projected but unsuccessful experiments then in progress at Magdeburg.

The probabilities are that passengers will not travel in rockets until after these projectiles have been fully developed for carrying mail and express. Some daring venturer may then undertake to ride a large mail rocket, with such precautions for his comfort and safety as he may be able to manage. His minimum requirements will be an enclosed cell supplied with air at about sea-level pressure, continually enriched with oxygen and purified of excess carbon dioxide, and some shock-absorbing equipment in case of a hard landing. If the take-off acceleration is high, he will need to lie down in a spring-mounted hammock or cot. He will have to depend entirely on the auto- At the speeds it will have to reach, his reflexes would be too slow and erratic.

In the first flight it will probably not be possible even for the passenger to see where he is going. His quarters will be cramped; provision for windows and the like would add excess weight. Even if windows were provided, he would be able to see little. On the upward part of the trip he would catch only a vague glimpse of the ground, rapidly receding from him. Clouds and mists would soon obscure the familiar features of the earth. From the stratosphere the world would be completely buried in haze; the glare of the sun would hurt his eyes. Almost before he could adjust himself to these rapid changes, he would be on the downward journey again, approaching his destination so rapidly that he could catch only a hasty glimpse before the slowing rocket, coming in on its wings and vanes, would be seeking the landing place.

The first passengers will spend a cramped and terrifying few minutes far above the earth. They will have nothing whatever to say about the course of their flight or the ending of it. And very likely they will be glad enough when it is over.

II

ber of short mail flights have been made with success. If we can solve the difficulties in the way of developing long-range mail rockets, then passenger rockets would seem logically to be the next step. But human freight is somewhat more delicate than other kinds of cargo, and its transport by rocket raises physiological and psychological problems as well as mechanical ones.

The mechanical ones, for both mail and passenger rockets, are to a large extent the same. A rocket is propelled forward by the force of the jet expelled backward from its motors when fuel is burned inside them. The motors fire only during a relatively short part of the flight; then they cease to function and the rocket coasts along on the momentum they have generated. Hence the distance it can travel depends on the maximum speed it can reach, which in turn depends on the velocity of the jet expelled by the motors and on the amount of fuel the rocket can carry in proportion to its own weight.

In most cases a rocket which carries approximately twice its own weight in fuel can reach the speed of its own jet. The rocket's speed can be further increased by increasing the ratio of fuel weight to combined structural and payload weight, but obviously this can be done only with the expenditure of more and more ingenuity in design, and in any case at a loss of payload capacity—an essential factor where mail or passenger rockets are concerned. The speed can also be increased, of course, by increasing the speed of the jet—by using better fuels or more efficient motors.

At present we have standard rocket motors with a jet velocity of between six and seven thousand feet per second, but this represents less than half the theoretical velocity obtainable with such fuels as acetylene and liquid oxygen, and it has been exceeded in the laboratory. So we may safely assume that by the time we are ready for rocket mail and passenger service we will have motors with a jet velocity of eight thousand feet per second or better.

Without going beyond the bounds of possibility we may also assume that by that time we will be able to design, and actually manufacture, a rocket light enough and strong enough to permit a payload-structure-fuel ratio of 1 to 2 to 6—that is, to carry twice as much weight in fuel as the weight of the combined structure and payload.

Ready to fly, our rocket will weigh 9 tons. At the end of the firing period, having expended its entire fuel supply, it will weigh 3 tons. By that time it will have reached its maximum speed—the speed of its own jet—and will be cruising along in the upper stratosphere at about 8,000 feet a second. This speed will permit it to make a flight of around 400 miles—a little more than the distance from New York to Pittsburgh—though air resistance during the time it is cutting through the heavier atmosphere close to the earth's surface will reduce the distance slightly. About six and a half minutes will elapse between take-off and landing.

When it arrives at its destination, the rocket will discharge its cargo—one ton of mail or express, or something less than a ton of passengers. For if mail or express is carried, no special provision will have to be made for it except storage space, and the entire payload of one ton can be made up of the cargo itself. But if passengers are aboard, the extra equipment added to provide for their safety and comfort—equipment not structurally a part of the rocket—will have to be included in the one-ton allowance for payload.

WE HAVE already seen what minimum special equipment the first daring rocket passenger will need in order to keep himself alive through his journey: air to breathe and protective devices to enable him to endure the rapid acceleration of the take-off and the shock of landing. But in commercial rocket flying the comfort of the passengers will have to have closer consideration—and since rocket trips will be by no means cheap, there will have to be some luxury in appointments. The pressure cabin will have to be more than a glorified payload compartment. We shall have to count as part of the payload the weight of this cabin, the air-conditioning equipment, the seats or hammocks, the safety devices, the passengers' baggage, and such little touches as pillows, padding, drinking water, and the like.

We must also include in the payload the

weight of the pilot and his equipment—for whereas the mail rocket will have no need for a human pilot, presumably the commercial passenger rocket will carry one. Although he could have no control over the rocket during the first part of the trip, he could—as we shall see later—help direct it as it slowed down toward the end of its flight.

Since so many items must be counted in the payload, it is probable that only about four passengers and the pilot could be carried. Permitting them an allowance of 200 pounds each for persons and baggage, only 1,000 pounds will remain for all the rest of the equipment of the passenger compartment—a slender margin, but not an impossibly small one.

We have raised the question of the cost of the trip, and now we can look at that a little more closely. A concrete fact stands out: six tons of fuel will be required in such a rocket to transport four passengers from New York to Pittsburgh. The fuel will consist of liquid oxygen and acetylene or possibly gasoline. Twenty cents a gallon—roughly 2½ cents a pound—would perhaps be a conservative but reasonable estimate of its cost. This brings the fuel bill to $300 per trip, or $75 for each passenger.

It would be foolish to try to guess what the rocket itself would cost; or how many trips, in practice, it could make daily (even though we do know the actual flight time); or what costs would be involved in maintenance, rocket port operation, ticket sales, administration, overhead, taxes, allowance for depreciation, dividends to stockholders, obsolescence, insurance, provision for damage suits, and all the other necessary costs and charges that go to make up a large-scale transportation budget. But it seems safe to guess that the cost of a ticket from New York to Pittsburgh in the rocket I have just described would come to about $300 or $400 at the least.

Since the rail trip, with Pullman accommodations, costs only $20.77 and an airplane ticket, including transportation to and from the airports, comes to only $25.01, this is rather a steep price to pay for saving, at the most, two hours in travel time over the flight time of a through-route airplane. We do not need to assume, however, that this matter of cost automatically eliminates the passenger rocket. The 9-ton rocket in all probability would be a minimum size; using it would be about like trying to haul passengers profitably in a two-passenger airplane. If the size were doubled, the number of passengers to share the cost could perhaps be somewhat more than doubled. In an 18-ton rocket, we might be able to transport nine passengers; in a 36-ton rocket, possibly twenty—bringing the fuel expenditure per passenger down to just a little over a ton.

In the age of rocket power there will of course be in operation other fast jet-driven craft—utilizing the rocket principle in various ways but not themselves true rockets. There may be duct-engine gliders carrying passengers at 400 to 500 miles an hour, powered perhaps by athodyds. There will be stratosphere aircraft driven by turbo-jet engines, possibly augmented by duct engines, traveling as high as 600 to 700 miles an hour. There may be huge turbo-jet stratoplanes flying at altitudes of 10 to 12 miles, boosted through the higher portions of their flight by auxiliary rocket motors permitting them to go as fast as 1,500 miles an hour. However, the passenger-carrying rocket will present a form of speed competition impossible for others to reach. As against the dimly possible 1,500-mile-an-hour top speed of the rocket-boosted turbo-jet airplane, the rocket ship for long-distance flying will be able to make—indeed, *will have to make*—velocities as high as 7,000 to 12,000 feet a second at the end of powered flight—or more than 5,000 miles an hour!

III

Can human beings withstand such enormous velocities? Is it sane to think that people will subject themselves to such strains just to get rapidly from one point to another?

When railroads were first proposed, one of the objections raised against them was the menace to human life of travel at 15 miles an hour. When much higher speeds were promised by the early airplanes, it was frequently objected that the human frame could not stand such velocity. The human body, however, turned out to be a pretty tough article. As passengers on the space ship Earth we are at this moment riding around the sun at a velocity of almost 19 miles a second—yet we are not even aware of it. Actually, it is not velocity that affects the human body. What makes a difference is the *change in rate* of speed, either increase or decrease—in short, acceleration.

The upward flight of a rocket at the beginning of its journey is of course an accelerated motion, and in some types of rockets the acceleration may be as high as ten to fifteen times gravity—that is, the speed may increase ten to fifteen times as fast as the speed of a freely falling body. When we consider whether it will be possible for human passengers to ride in rocket ships, we must find out, first, what is the maximum acceleration that human beings can stand, and second, what starting acceleration would be needed in a rocket suitable for passenger use.

The ability of human beings to tolerate acceleration has already been the subject of some research, since it is a factor in establishing the speed at which a dive bomber can attack and pull out safely. It is generally accepted that a healthy, normal young man can stand an acceleration of six to seven gravity (192 to 224 feet per second each second) without serious effect, though many men temporarily "black out" at accelerations above this point, owing to reduced blood pressure in the brain. Blacking out, even at nine gravity or higher, can usually be prevented by a prone position relative to the force of acceleration. Under suitable posture and other conditions it is probable that normal, healthy human beings can stand ten gravity or more if the time is short.

The subjective effect of acceleration is simply a sensation of greatly increased weight. This, however, may be quite distressing, and the average civilian passenger will not relish being subjected to acceleration much beyond three or four times gravity. If he normally weighs 150 pounds, a passenger subjected to an acceleration of three gravity will feel as if his weight had suddenly been increased to 450 pounds. This is quite a load. He will be able to tolerate it, however, if he is lying down and is required to do no physical work. At four gravity, his weight will seem to be 600 pounds, and at five, 750 pounds. These pressures would probably be insupportable to most people; it would be impossible to breathe except with the greatest effort.

From all this we can conclude that the maximum practical average acceleration permissible to a passenger-carrying rocket would be about three or four times gravity, or 96 to 128 feet per second each second.

Now it happens that this figure also works out well in the design of large rockets intended to fly through the atmosphere. For while it is theoretically most advantageous in rocket operation to discharge all the fuel in the shortest possible time, it is also more efficient to discharge fuel in a vacuum, or in the very thin upper atmosphere, than to discharge it in the heavier layers close to the earth where resistance is high. So if the rocket is intended to leave from the surface of the earth, we must make some compromises with air resistance. Fortunately for the future of the passenger rocket, when we calculate what these compromises should be, we find that a long-range rocket, everything considered, should have an average acceleration of about three times gravity.

We may therefore accept it as a safe guess not only that a passenger rocket could be manufactured which would transport human beings over long distances at mile-a-second speeds, but that the passengers would be able, under most circumstances, to withstand without too much discomfort the acceleration involved.

IV

Of course this is not the whole story of the effects of rocket flight on human beings. The psychological difficulties might well be less easy for the passengers to take than the physical ones.

The rocket is accelerated for only a brief part of its flight—the first minute or two will be quite enough, at an acceleration of three gravity, to provide the velocity needed. The fuel having by that time been expended, save for enough to slow the rocket at the end of the flight, and for steering en route, the motors will cease operation. Instantly the passengers will pass over from a condition of accelerated flight, in which their normal weight will appear to have been multiplied three times, to a condition of what the physicists call "free fall." In this period, so far as the passengers and all other items in the rocket are concerned, *there will appear to be no gravity acting at all.*

Absolute weightlessness is a condition to which no human being has actually been subjected, and consequently we have no way of knowing how the human system will respond to it. Possibly, except for the inevitable readjustments of circulation, accompanied by some momentary dizziness, there will be no unpleasant physical effects. But there are bound to be psychological ones, the extent of which we cannot now judge.

For the state of weightlessness is approached in human experience only in falling. In flight it may be accompanied by a state of terror the like of which no person has ever before been called upon to face. Most of us are mortally afraid of falling. It is a fear acquired early in life and it never leaves us. Yet two or three minutes after taking off from the rocket port of the speculative future our passengers will be plunged into it en masse. What is more, the experience will endure for a relatively long period of time, depending on the distance of the flight.

The sensations of fear accompanying free fall will be matched by some other queer experiences. Since everything in the rocket ship will be in free fall with it, none of the objects riding with the passengers will seem to have weight either. Our lives are so conditioned to things as they normally behave on earth, with gravity holding everything in its place—causing liquids to flow downhill, balls to roll from higher levels to lower, and all solids to stay in place because of their weight—that our passengers will be astonished indeed to see how familiar objects perform in the period of free fall during rocket flight.

Assuming they are hungry, and food is available, they will find it out of the question to eat solids from open plates or to move them to the mouth in ordinary spoons or forks. When pushed or disturbed in any way, food will simply float away in the direction of the push. Unless pierced by the tines of the fork, it will not hesitate at the mouth but will waft on gently upward and land against the ceiling. If nourishment is to be taken at all during the journey, it will have to be served in collapsible tubes, like toothpaste, and squirted directly into the mouth. Liquid in open containers will be impossible to drink. A glassful of water will float up out of the glass in a round globule. If it is touched, its surface tension will cause it to crawl wetly over the person or object contacting it, like some squashy and sentient amoeba. Liquids will have to be served from collapsible containers like hot water bottles or the wineskins of the Spaniards.

The passengers will have to be strapped to bunks or hammocks. If they attempt to walk about during the period of free fall, they will more likely bump their heads against the ceiling than progress in the desired direction. Of course, for the pilot there should be toe straps in the floor to engage his feet one step at a time—or possibly he might be supplied with steel-soled shoes magnetized sufficiently to cling to the steel floor of the cabin.

During flight the passengers will be able to see little of the earth even though portholes are provided. At the height of the flight, the trajectory will carry the ship well into the stratosphere and perhaps even into the aurora zone. The features of the earth will be misty and vague, but the passengers will be able to view the sun and stars as an astronomer would like to see them—without the light-absorbing blanket of the air. The sky will appear black, or bluish black. The stars will be plainly visible, even though the sun is shining. The solar rays on the side of the ship will probably make it uncomfortably hot, unless some means is provided for cooling—perhaps by rotating the projectile gently to let the warm side radiate away its heat.

V

THERE is at least one more experience facing the passengers before their journey is done. What goes up must come down. If the projectile is carrying human freight, it cannot come down as rapidly, or as bumpily, as it could if the payload were merely mail or express.

To match the acceleration of the upward flight, the rocket ship will now need to decelerate. A common suggestion for slowing the rate of deceleration—for easing the fall—is to restart the motors, this time in reverse, so that the jet is expelled in the direction of flight. This would, of course, require the expenditure of more fuel, a supply of which would have to be saved for the purpose.

Here we run into real difficulties. It would not take anything like as much fuel to stop the ship as it did to start it, for the rocket burns up a major part of its weight in the first minutes of flight. Nevertheless, if fuel is required to do the whole job, the results are disastrous to our project. The starting weight of our loaded rocket (the twenty-passenger size) was 36 tons. Twenty-four tons of this mass was burned to provide velocity for the trajectory, leaving 12 tons to make up the weight of passengers, construction—and fuel to bring the projectile to a suitably gentle stop.

But the fuel-weight *ratio* for stopping would have to be the same as it was for starting. So of the 12 remaining tons, 8 would need to be jetted out of the motors in the direction of flight, in order to reduce the speed of the final mass to zero. The final weight, therefore, would be 4 tons. But 4 tons was the total weight of our projected payload alone, so we are confronted with the quite impossible task of constructing the rest of the rocket out of nothing at all!

At this point ingenuity must come to the fore. Why not make the atmosphere do the stopping for us—adding a few dozen miles or so to the length of the flight into the bargain? We can do this if we equip the rocket with a set of retractable wings and tail surfaces, folded into its body during the beginning and middle phases of the flight, and now opened out as the projectile falls toward the earth. In the lower stratosphere the density of the air, at the high speed of the falling rocket, should be enough to make the wings take hold. The rocket is mostly empty now, and its comparatively light shell should itself provide some lifting surface when the wings give control.

Here too is where the pilot, who had nothing to do earlier but reassure the passengers, begins to earn the extra fuel his passage has cost. He now becomes the captain of a 12-ton glider. It is his responsibility to nurse the last yards of the distance out of the glide and bring the ship as gently as an angel to its berth at the waiting rocket port.

You are entitled to believe in the practical development of the passenger rocket ship or not, as you please. But you cannot dismiss it as an impossibility. If new applications of the rocket principle follow the sequence specialists now foresee, there is no logic in concluding that this final step cannot be taken too. Some day your children or your grandchildren may be able to take off from Paris for New York, or from Los Angeles for Honolulu, and fly faster than the sun, watching the day grow younger as they move.