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Potential New Technologies

*by Edward J. Ward**

President Johnson signed the High Speed Ground Transportation Research and Development Act on September 30, 1965. Under the authority of that act the first ground transportation R&D program in this country has gotten underway.

During the time since the signing of the act, much effort has been expended in a review of available technology and of the suggestions for new transportation systems which have come from every conceivable source. Some have come as company-sponsored proposals, some from inventors as potential ideas, some literally on the backs of envelopes and others through visits. From the review of the state-of-the-art and evaluation of suggestions, a plan has been distilled through a liberal use of "engineering judgment." The plan includes the pursuit of a number of new technologies which appear to have the potential of developing into improved transportation systems in the not-too-distant future.

One of the first conclusions reached was that ground transport systems capable of speeds up to and over 300 mph are technically feasible. This conclusion caused a re-examination of every function in a transportation system. Naturally, the propulsion function drew major consideration.

ELECTRIC PROPULSION

Electric propulsion has sufficient advantages, not the least of which is the reduction of air pollution, to merit a number of research projects.

1. Power Collection

Both rotating and linear electric motors (if the stator is in the vehicle) require power to be transferred from stationary wayside structures to the moving vehicle. Today, this transfer is accomplished by means of a shoe and third rail at lower speeds and a pantograph and catenary for higher speeds. Pantograph-catenary systems work well at speeds up to 150 mph and may be satisfactory up to 200 mph. However, as speed increases so does the difficulty of maintaining constant contact and thus a constant supply of power. Several means to provide a steady flow of power have been proposed.

The first is a servo-driven pantograph to replace the spring-loaded types now in use. Constant tension devices and improved catenary designs to maintain the conductor wire at a constant height have done much to eliminate contact breaks, when the pantograph spring is unable to react quickly enough to a change in wire height. However, when multiple self-propelled units are used, the leading pantograph sets up oscillations in the conductor wire and following pantographs act as amplifiers. Servo-driven pantographs could

**Office of High Speed Ground Transportation, U.S. Department of Commerce.*

permit operation with much lower pressure against the conductor and thus reduce the amplitude of the oscillations as well as wear, and with the faster reaction prove superior in maintaining contact.

The other suggestions are all for non-contact transfer and thus have chosen to avoid the maintenance-of-contact problem rather than try to solve it.

Some of these concepts are (Ref. 1):

1. Gaseous Condition in an Arc—

Power is transferred from a distribution line to the vehicle in an arrangement resembling a pantograph-catenary. D.C. or A.C., single phase or polyphase, could be transferred in the form of an arc perhaps 1/2" to 1" long, which might dissipate 9 to 18 KW of power. Such a configuration needs techniques for aerodynamic shielding, magnetic or electrostatic arc focusing, and electromagnetic directional driving.

2. Inductive Coupling—

Wayside structures, acting as the primary of a transformer, could be inductively coupled to a car mounted structure, acting as the core and secondary of the transformer. The stationary structure could be several hundred feet long consisting of a few turns. An array of such structures could be energized sequentially as the train passed. High frequencies of 6,000 or 7,000 Hz would be needed.

3. Capacitive Coupling—

Power is transferred through the dielectric of space. Wayside structures could be an array of 10 to 20 plates of sheet metal about 12 to 24" wide, spaced about 3" apart. Plates about 100 feet long would be mounted on the vehicle to interleave with the stationary plates without touching. The requirement is for minimum spacing compatible with vehicle motion tolerances.

4. High Frequency Electromagnetic Waves—

Transferring power can be accomplished by radiating electromagnetic waves. The coupling becomes more efficient at higher frequencies. Frequencies from the mega Hertz to microwave (10^6 to 10^{10}Hz) should be considered. An enclosed wave guide or two-wire guide might be used. In tube vehicle systems, the wall of the tube could be used as the wave guide (Ref 2).

2. Linear Motors

As mentioned earlier, the techniques just described can be used for linear electric motors. Linear motors are being used for door openers and toys, where power levels are low, but have not progressed beyond the laboratory in the range of power required to propel even a small vehicle (Ref 5).

Linear motors deserve consideration for a number of reasons, including the lack of moving parts, less weight in the vehicle and the ability to be used for vehicles without wheels.

The term linear motors. just as rotating motor, includes variations in electrical arrangements, i.e. induction and synchronous. Peculiar to linear motors is the possibility of interchanging the armature and windings. Placing the windings in the vehicle or in the right of way changes the nature of the operation significantly. If the windings are in the right of way, there is no power transfer to the vehicle. Even at present prices the cost of placing copper coils in a double track for a distance of several hundred miles is high, and in fact, the amount of copper consumed could be large enough to disrupt the entire copper market. Unless new information is uncovered, the conclusion must be reached that the windings must be in the vehicle, in spite of the power collection problem.

The only exception which seems possible is to use short sections of linear motor as a "booster" system to supplement on-board vehicle systems, into and out of stations (both acceleration and dynamic braking can be provided).

Linear motors of both the induction and synchronous types are being investigated (Ref. 6). The linear synchronous motor offers the advantage of high-power-factor operation and improved efficiency at larger air gaps. Since the air gap between coils on a moving vehicle and the armature in the guideway cannot conceivably be controlled to the close tolerances of rotating motors, larger air gaps are unavoidable. Synchronous motors will require more complex control circuitry and to take full advantage of their characteristics over a wide range of vehicle speeds a variable frequency power supply is implied. However, such a power supply is also desirable with the induction motors as it allows running at a controlled amount of slip, and thus provides maximum reaction at all speeds.

The induction motors are less complex, more rugged and reliable and consequently less expensive.

Both the linear induction and synchronous motors suffer by comparison to their rotating counterparts due to their non-symmetry, caused by the end effects of the linear configuration. Unlike a rotating machine a three phase linear machine cannot produce a uniformly distributed flux and will not draw balanced three phase currents, resulting in a slight degradation in performance.

Linear induction motors have been shown to have a figure of merit which is proportional to the square of the pole pitch times the operating frequency, and inversely proportional to the air gap width and secondary resistance (Ref 5). For speeds in the 300-500 mph range air gaps in the order of tenths of an inch are practical from the motor efficiency point of view. The vehicle need not be confined by the guideway to such small movements, because the windings can be suspended from the vehicle to "ride" the armature, possibly using air bearings to maintain the air gap clearance. If, however, larger air gap tolerances are required, the synchronous linear motor can be employed.

3. Fuel Cells

A very different aspect of electric propulsion which should be pursued is battery or fuel-cell-powered automobiles or "multi-modal" vehicles.[1]

1 An example of this type of multi-modal vehicle is the Alden StaRRcar (Ref. 4) which is designed to operate on city streets as a conventional automobile and then enter a special guideway, pick up electric power from a third rail and be guided automatically from suburbs to city center or between cities.

Hoffman, in a RAND study (Ref 3), foresees electric automobiles very similar to present models in that the body, wheels, suspension, seats, etc. could remain basically unchanged if a battery or fuel cell and electric motors replace the internal combustion engine. The Post Office and some companies with a similar short range delivery service, such as dairies, have used electric trucks. If electric automobiles are to gain wide acceptance, motorists must be able to drive at least as far on a single charge as is now possible on a tank of gasoline, at least 200 miles. Hoffman recommends a fuel cell development program aimed at automotive applications.

TUBE VEHICLES

As the speeds of ground transport systems increase, safety and all weather considerations make a protected right-of-way increasingly attractive. The ultimate in protection is an enclosure or a tube.

1. Differential Pressure Propulsion

Tube vehicles may travel on wheels or be aerodynamically supported. In either case, as the vehicle moves through the tube, masses of air pile up in front of it, that is, the vehicle acts as a free piston, which places large power demands on the propulsion system. The ratio of the vehicle frontal area to the cross section of the tube is an important factor as the power consumption raises exponentially with the ratio. One way to overcome this effect is to do as aircraft do, travel in less dense air. While an aircraft climbs to high altitude to travel in thin air, the tube can be evacuated to accomplish the same end.

An evacuated tube makes possible propulsion of the vehicle by admitting ambient air pressure behind it and using the pressure differential as the propelling force. This has been suggested by Edwards (Ref 7). The movement of large quantities of air through long tubes may result in significant friction losses in the boundary layer against the tube wall.

An interesting sidelight on the tube, or actually tunnel, vehicle proposed by Edwards is his concept of a flexibly supported tube to provide a resilient surface, reducing the impact loads experienced by wheeled vehicles. One flexible support conceived is an inner tube floating in water contained in an outer tube.

F. T. Brown (Ref 8) has completed an analysis and experimental studies which indicate that damping must be designed into such a system or resonate vibrations may be set in motion by a critical vehicle velocity which is in the operational range. The calculated critical speed for Edwards' configuration is 262 mph. Edwards proposed an alternate supporting system which might avoid this problem.

Another proposal has been advanced to use differential pressure created by raising the vapor pressure behind the vehicle without admitting additional air in a partially evacuated tube. This can be done by either subliming a solid chemical into a gas or boiling a liquid with the heat supplied from the rear of the vehicles. Also, by liquefying the vapor in front of the vehicles, the pressure buildup can be decreased. These are ideas being studied by Celestial Research (Ref 9). If these ideas are technically feasible, drag can be minimized and the process will require less costly and smaller capacity vacuum pumps than a pure vacuum system.

2. Crypto Steady Pressure Exchange

There is still another concept to propel vehicles through tubes proposed by Dr. Joseph V. Foa of Rensselaer Polytechnic Institute (Ref 10). Dr. Foa's idea is to alleviate the piston action by moving the air from in front of the vehicle to its rear and leaving the air relatively undisturbed except in the transfer region. Whereas external propulsion such as wheels, linear motors, etc. cause the transfer by movement of the vehicle, an "internal" propulsion system generates thrust by the transfer. Propellers, fans, turbojets or ejectors are internal propusion systems. A novel design of Dr. Foa's is to use "crypto-steady pressure exchange." A pressure exchange takes place in cryptosteady situations involving two or more flows. Injection of air into the front of the vehicle and ejection from whirling slots in the rear will form a vortex and act as a "bladeless" propeller.

This mode of propulsion and others, along with various arrangements for aerodynamically supported vehicles in tubes, will be investigated experimentally in a model test facility at Rensselaer. A 12 inch diameter 2000 ft. long tube with proper instrumentation is now being used for this purpose.

Theoretically, tube vehicles can travel at supersonic speeds, but because of the severe problems of high temperatures and shock waves, the decision has been made to confine studies to subsonic speeds at least in the first phases of the High Speed Ground Transport R&D program.

3. Tunneling

Up to now the discussion has concerned vehicles in tubes, but the tubes can just as well be tunnels. The rising cost of land has already brought the cost of surface routes in the centers of large urban areas generally above tunneled routes. Tunnels have well known additional benefits of preserving historic landmarks, prosperous business establishments and pleasant residential areas. Furthermore, the shortest route can be chosen, particularly if the tunnels are deep enough to pass under utilities.

As land costs will no doubt continue to rise, tunnels are expected to be important to any future ground transportation system.

Today, tunneling is done primarily by drill and blast, but recently some tunnels have been bored with machines (Ref 11 & 12). Results are encouraging for reasonable improvements in the rate of cutting and reduction in cost. The Bureau of Reclamation on the Navajo irrigation project is boring through sandstone which is relatively soft, having a compressive strength of about 6000psi. Two tunnels are being cut, one a 17-1/2 ft. horseshoe by blasting and the other, a 20 ft. diameter round by boring machine. The conventional tunnel experience has averaged 50 ft. per day, while the boring machine has averaged 60-1/2 ft. per day.

Another boring machine was tried in the New York City water tunnel between Brooklyn and Staten Island. The machine worked well in granite but the spoil removal could not remove the cuttings when shift was encountered (Ref 13).

The machine experience indicates any new design must include the whole tunneling system—rock cutting, spoil removal, crew protection, etc., and cutters must be able to cut many types of rock, not just one. Perhaps, additional research on cutter design may produce the second. However, other new and novel means of excavation deserve consideration. Chemical, thermal and hydraulic methods will be investigated.

Research at MIT (Ref 14) has shown chemicals can weaken rock, so that this may be a solution rather than the usual approach of increasing the power of the cutting device.

Experiments show that after exposure to any of several different methods, the rate of crack propagation increased, while the surface energy required for failure and the tensile strength decreased. If only the tensile strength is affected, then new methods of cutting must be used in combination with the use of chemicals, since present cutters apply compressive stress.

Moavenzadeh, Williams and Wissa in the same investigation have also shown the effects of combined chemical and thermal treatment on tensile strength. For example, as much as a 50% reduction in the strength of granite was experienced with thermal cycling up to only 90°C with the application of a 1% water solution of aluminum chloride.

Flame jets appear to be the most promising of the thermal methods, being currently used in quarries and taconite mines. Plasma jets were not selected because of the large power requirements. A study of the flame jet approach will be made in the near future. The entire tunneling system—cutting, mucking, and environmental protection of the crew must all be considered.

The other method which we have chosen to study is the use of cavitation in hydraulic jets (Ref 15). Cavitation damage to marine propellers indicates air bubbles in water jets may increase the cutting action significantly.

A facet of tunneling which should be considered and may be the deciding factor as to whether or not tunnels are practical is the multiple use of a tunnel. The outer shell of a vehicular tunnel can be used for the transportation of water, petroleum products, communications or even mail. Sharing the cost of a tunnel among two or more users certainly should make the prospect more attractive.

AIR CUSHION VEHICLES

Ride quality at high speeds naturally is a major consideration in any ground transport. The limit on speed of railroads may not be determined by pure technical factors such as wheel adhesion which decreases as speed increases, but by the difficulty and expense of maintaining running gear and roadbed to near perfection.

The answer may be to eliminate the wheels and use air to support the vehicle. A vehicle supported on a cushion of air has a much greater tolerance to imperfections in the surface over which it travels than does a wheeled vehicle. A cushion of air may well be the most effective and yet simplest vehicle suspension.

It is true that the power required for levitation is greater than that to overcome rolling resistance. But at speeds above 150 mph aero-dynamic drag is the predominant consumer of power.

The absence of wheels will solve the ride quality problem but it creates another in that air cushion vehicles are difficult to guide. Unless new methods of control can be developed, guideways are needed for common carrier operations over land.

Many configurations of air cushion vehicles have been proposed, ranging from low air pressure and large clearance above the surface to high air pressure and small clearances. Also, flexible diaphragms, skirts and peripheral jets have been introduced to retain the large clearance but to reduce the volume of the air flow. Other configurations use ram air to augment or replace internally supplied air for levitation once a high enough speed is reached. Another suggestion has been to operate at low speeds on wheels and lift off the running surface when the ram air pressure is sufficient (Ref 16).

Several conclusions have been drawn from the work to date:

1. Vehicles with very small clearances, which might be called air bearing vehicles, require guideways of extreme accuracy or a high degree of smoothness and therefore retain the inherent disadvantages of the wheel. This may be the reason Ford abandoned its "Leva Car" several years ago.

2. Large clearance, low pressure configurations appear to be aerodynamically unstable when reaching speeds which produce ram air pressures above the air cushion pressures. This problem may be solved through the use of peripheral jets in the form of jet flaps which can control or take advantage of ram air pressure.

3. Because of the low requirement for accuracy of the guideway surface and the lack of concentrated loadings, the construction costs for air cushion vehicle guideways could be lower than for any other form of ground transportation suggested up until now.

R&D programs on tracked air cushion vehicles are now underway in England, France and this country (Refs. 17 & 18).

The tracked Hovercraft under development by Hovercraft Development Ltd. in England uses peripheral jets and linear induction motors. Linear motors appear to be uniquely suited for tracked air cushion vehicles. A six foot model has been operated on a loop track.

The French program under Bertin et Cie is now evaluating a half scale model of their "Aerotrain" operating on a seven mile test track. The vehicle is powered by a turboprop and has run up to 125 mph. The air cushion is the flexible skirt low pressure type. The guideway is an inverted tee with the leg of the tee extending into the underside of the vehicle. Small wheels bear against the leg for guidance.

COMMUNICATION AND CONTROL

No high speed transportation system can be operated unless communications can be established with the moving vehicle, information received from the vehicle and commands transmitted to it, permitting control to be established. Various transmission channels have been considered for this purpose (Ref. 19).

Radio is the most obvious method, but due to the large number of simultaneous transmissions of information required for central control, wayside control, surveillance of the right of way, vehicle to vehicle communication and passenger telephone service, not to mention TV and radio for entertainment of passengers, sufficient frequencies are not available.

The Japanese National Railways have experimented with a leaky wave guide along the entire route providing all the channels needed plus surveillance, but the high cost has discouraged any operational installation (Ref. 20). Others have experimented with the use of the surface wave around a conductor, particularly Barlow for the British Railways (Refs. 21 & 22). A study has been started by the Environmented Science Services Agency laboratories at Boulder, Colorado to identify the most promising approaches on which research should be started.

SUMMARY

The reviews and studies of the Office of High Speed Ground Transportation made to date have resulted in decisions to explore the areas described. As further studies are completed, other areas may turn out to hold just as much promise and, if so, additional research projects will be initiated.

To assist in these reviews, the Assistant Secretary of Commerce for Science and Technology, J. Herbert Hollomon, has appointed an ad hoc panel of the Commerce Technical Advisory Board to review the technologies in high speed ground transportation for the purpose of recommending where additional research projects would be worthwhile.

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