paper sent to the 5th World Conference on Transport Research, session G-4 151-1.
Yokohama, Japan, 10-15 July 1989

RESEARCH AND DEVELOPMENT OF A NEW TRANSPORT MODE IN SOUTHERN BRAZIL

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ABSTRACT

An innovative urban transport mode is being developed in Brazil. The so-called Aeromovel system was originally conceived by the mid 70's. The system consists of vehicles travelling on elevated trackways. The main difference between Aeromovel and the more conventional automated people movers or monorails resides on its pneumatic propulsion. A high-speed airflow, generated by stationary units located along convenient intervals, acts on the blocking surface of propulsion plates rigidly connected to the vehicles. The trackway comprises prefabricated modular concrete tubes. The upper surface of the tube has a longitudinal slot that provides passage to pylons connecting propulsion plates moving inside the tube to the vehicles. Vehicles ride on top of conventional rails which are fixed to the upper plane of the tube. The speed of the vehicles is determined by air pressure differential which is controlled by means of valves located at generator units and along the trackway.

Apart from general features arising from elevated systems, such as little traffic disruption during construction, interruption-free ride on exclusive right-of-way, and minimum interference with ground traffic, AEROMOVEL offers a series of important additional advantages. External propulsion enables the operation of light vehicles (dead weight of only 29 kg/passenger) which in turn results in comparatively lower investments for building the trackway. As traction is independent of the wheels, AEROMOVEL overcomes the limitations imposed by the interaction between steel wheels and rails during acceleration and deceleration stages. The non-energised trackway can be used as an evacuation path for the passengers. Also from the safety point of view, the air buffer between propulsion plates would minimise or even impede the collision of successive vehicles.

A series of studies commissioned by the Ministries of Transport and Science and Technology have been conducted by UFRGS - the Federal University of Rio Grande do Sul, Brazil. They cover a wide range of aspects, such as safety and reliability aspects of key components to the general performance of the system as an alternative public transport mode. The methodology included extensive field data collection and the development of computer simulation models.

The paper describes the AEROMOVEL system in terms of its concept, operation, research and development over the last years. The main features and advantages of the system are focused in terms of its application along urban corridors. The conclusion stresses:

(1) the importance of research in the technological development of the system and also in detecting the potential market for the system.

(2) that there is scope for developing new modes that can favourably compare to more sophisticated and expensive alternatives.

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1. INTRODUCTION

Over the last years several new transport technologies have been developed. As many of them differ from the more traditional ones, mainly due to some innovative concepts, they are referred as non-conventional modes. Different authors use alternative denominations to classify them: Monorails, Automated Guided Transit, Light Guideway Transit, Automated People Movers, etc. The application of such non-conventional modes is not limited anymore to airports. university campi or recreational centres where they tend to be lines with a very limited number of stations.

Several cities already employ such innovative modes as part of their public transport network, whilst others have plans to implement them in the near future. In 1985 (1) some 1000 million dollars where being invested in the construction of the automated people movers of Miami, Detroit and Vancouver. Japanese monorails date to the 70's, being mostly used as feeding systems to railway stations; in mid-sized cities they cross central areas in radial lines. In 1985 (2) eight monorails were being implemented in Japan while eight systems were already in operation.

There are at least three key issues related to the concept of new public transport modes operating along elevated trackways. Firstly is the dichotomy within the transport community that separates those who consider that the fundamental concepts of all technologies have already been developed and therefore research efforts should concentrate in developing them and a smaller group of individuals who contest this position by proposing new ideas and concepts. This situation is aggravated in the developing world where very limited funds are allocated to research and development. The second issue is the controversial location of the trackway. For the users the best situation is to have stations located on the ground level thus avoiding inconveniences caused by ramps, stairs, escalators and lifts. Many proposals for systems that operate on elevated trackways face strong opposition from those who believe they cause visual disruption to the environment while others understand they are a positive element in the process of developing or revitalising urban areas. Thirdly is the cost of innovative technologies. In some cases the range of uncertainties associated to introducing a sophisticated new technology have led to a gross underestimation of the implementation costs.

This paper introduces an innovative public transport technology being researched and developed in Southern Brazil. The so-called 'Aeromovel system' aims at overcoming one of the key issues already mentioned, i.e. the cost. The simplicity of the elements involved in its conception characterises the Aeromovel as an important new contribution to the group of automated people movers.

2. CONCEPT OF THE AEROMOVEL

The Aeromovel system uses the pneumatic concept. Pneumatic propulsion for passenger transport was introduced in England during the last century. Day and Wilson (3) describe some of the pioneer systems which were based on the use of high levels of air pressure on metal tubes sealed by leather and wax of animal origin. At those days the main pitfalls of the systems were related to the incompatibility between the proposed concept and the technological development of the materials. There are many differences between the Aeromovel and the early systems and patents have been awarded to the developer, SURCOESTER, in many developed countries of the world, including the United Kingdom.

The propulsion of the vehicles is effected by airflow generated by stationary units installed at convenient intervals along the trackway. The propulsion sub-system consists of a series of valves and tubes connected to a centrifugal fan. By alternating the position of the valves either pressure or suction is generated on the sealed tube. Figure 1 depicts the key elements of the system.

The trackway comprises an elevated concrete tube with a constant square or rectangular section. It is composed by pre-fabricated modular beams supported by a series of pillars. The upper surface of the tube is provided with a longitudinal slot sealed by an elastic rubber-based component. Along the slot runs the pylon that connects the plate, the element that runs inside the tube with the action of air pressure differential, to the vehicle that travels outside the tube.

The vehicles are provided with steel wheels and ride on conventional rails which are fixed to the upper surface of the tube. The airflow level on the different sections of the tube, which is generated by the stationary units, is centrally controlled and supervised by operators located at specific stations. Automatic control is achieved by a series of interface modules located along the trackway, all connected to microprocessors.

3. FEATURES OF THE AEROMOVEL

Apart from a reduction of air pollution when substituting internal combustion engines, monorails and other similar transport modes present a series of characteristics intrinsic to the overhead location of the trackway, i.e.:

i. an interruption-free ride over an exclusive trackway and no interference with street level congestion which helps to attenuate the traffic of pedestrians and vehicles in general;

ii. an alternative supply of public transport in dense urban areas as the pillars that support the trackway can be spaced as to minimise the disruption of the activities at the ground level;

iii. lower investments in land acquisition as the trackway can follow the existing road network;

iv. minimum traffic disruption at ground level during construction of the trackway as modular elements can be built elsewhere for further on-site assembling.

Aeromovel presents some additional advantages to the ones just described; amongst them:

i. a safer use of a non-energised trackway as an evacuation path for the passengers during service disruption;

ii. an extra safety element that is intrinsic to the concept of the system as the air buffer between propulsion plates would minimise or even impede the collision of successive vehicles;

iii. a form of traction that is independent of the wheels and therefore capable of overcoming limitations in adhesion imposed by the interaction between steel wheels and rails during the acceleration stages;

iv. a low rate of dead weight per passenger which reduces the costs of constructing the trackway of the system.

Neuman and Bondada (1) note that the costs of constructing the trackway respond for some 60 to 80% of the investments required for implementing elevated systems. Therefore the weight of the vehicles plus the dynamic effects related to the form of propulsion of the vehicles define the robustness of the supporting structure which is a crucial element for every elevated system. Table 1 shows some general data compiled from UMTA (4) and local transport operators. Amongst the different public transport modes, Aeromovel is the lightest one with only 29 kg of empty vehicle per passenger being transported - considering existing seats and a peak occupation rate of 8 passengers per square metre of standing area for every system being compared. The low dead-weight results from the non-existence of a propulsion system within the body of the vehicle, which implies a simple bogie and the utilisation of light materials.

4. PILOT LINE

Investigations of the Aeromovel concept started in 1976 when a rudimental single-passenger vehicle was fitted to a 30 metres long trackway. Since 1979, with the participation of EBTU, the agency of the Ministry of Transport in charge of the Brazilian urban transport policy, Aeromovel has developed from scale models to field implementation. A 550 metres long experimental line with a 15 metres radius curve and a 5 per cent gradient, operated by a 16 seat-vehicle, formed the basis for the first set of performance tests. The second development stage started in 1981, with the construction of a full-scale elevated trackway where a vehicle for 150 passengers was inserted. After a short period of tests, the metropolitan transport authority of Porto Alegre identified a few locations for the construction of a pilot line.

The project of the pilot line comprised the construction of a 1060 metres long elevated trackway provided with a tube of 1 square metre of internal section. Work started by the end of 1982 along an avenue that circulates the central area of Porto Alegre, the 1,5 million inhabitant capital of Rio Grande do Sul, the southernmost state of Brazil. A comprehensive evaluation test was contracted by the Ministry of Transport in 1984 when only one station and a 650 metres straight section of the trackway were completed. Due to lack of federal funding, construction work was only resumed in 1987, with the introduction of a curve section, another station and signalling control to enable automatic operation.

By mid 1988 a private Indonesian company demonstrated interest for developing a 290 km-long network of Aeromòvel in Jackarta. Construction is already under way with the first section of 3.2 km-long 6 station-circular line in Taman Mini being due to become operational by the end of April 89. The second line to be constructed will link Kota to Block-M covering a total extention of 28 km; work will start soon after opening the Taman Mini line.

5. TECHNOLOGICAL DEVELOPMENT

Every development stage was succeeded by evaluation studies. As every stage was characterised by the design and construction of a new trackway line, the main objective of the studies was to obtain parameters and test new concepts that would be developed and incorporated to the next stage. The evaluation process itself was also evolving; early reports employed a totally theoretical methodology centred on analytical equations to investigate the pneumatic concept. The studies conducted after 1984 are centred on the collection of field data and the formulation of performance models to simulate the behaviour of the different subsystems.

The objectives, methodology and results obtained over the last series of studies are documented on a series of reports issued by FUNDATEC, the Technological Institute of the Federal University of Rio Grande do Sul and by IPT, the Institute for Technological Research of the State of São Paulo. Amongst others, they cover aspects such as the static and dynamic performance of the vehicle and the trackway, the operation and control of the system, the capacity of transport, the energy consumption, the performance of the stationary propulsion units.

6. SIMULATION OF THE AUTOMATIC OPERATION

One of the key studies (5) attempted to simulate vehicle operation along sections of the trackway separating consecutive passenger stations. The kinematic performance of the vehicle, established from site data collection employing accelerometers, formed the basis for the formulation of an analytical model. The model, once implemented in a microcomputer, enabled the simulation of the automatic operation, i.e. the interactions between vehicle sensors located along the trackway, microprocessors installed inside and outside the vehicle and different levels of air-flow pressure generated by the stationary propulsion units.

The automatic control was designed as to allow constant journey times for vehicles travelling along different sections of a line. In other words, the time taken by an empty vehicle to move between any successive stations shall be roughly equal to the journey time required by a fully loaded vehicle travelling on the longest section of the same line. Due to characteristics inherent to the pneumatic concept and the light weight of the vehicle, the acceleration profiles vary with the internal loading factor. Consequently, different speed vs. distance profiles have to be programmed and stored for every section of the trackway. Figure 2 presents a series of dots, each representing an alternative desired speed level at a particular sensor on a 520 metres long section separating successive passenger stations.

The computer drawn curve of figure 2 indicates the kinematic performance of a vehicle loaded with 268 passengers. The discontinuity of the curve results from the changes in the pressure levels inside the tube. The control program is based on a considerable number of decisions undertaken by the microprocessors each time a vehicle crosses one of the trackway sensors. Other performance indicators are also shown in the figure: total travel time (s), total (kWh) and specific (kWh/pass.km) energy consumption, average and maximum speed (m/s) and average acceleration (m/s.s).

The kinematic profiles form the basis for the investigation of the transport capacity of the system. A specific computer model is being formulated for simulating the operation of a complete line. It will enable the operator to test alternative control techniques and check, on an on-line basis, the consequences of altering speeds, headways, and changing the supply of vehicles in the line. The performance indexes will include energy consumption, passenger waiting times at the stations, average and total travel times and overall system capacity.

7. COSTS OF THE AEROMOVEL

Every public transport mode has capital and operational costs which are intrinsic to the location where its introduction is being considered. Even for the more conventional systems, measures of effectiveness taken in isolation, like capital costs per passenger, energy and maintenance cost per passenger vs. kilometre, are not directly comparable if it is not clearly stated the circumstances prevailing at the time and place the figures were obtained. In short, comparisons between alternative urban transport modes are meaningless if not pursued under identical circumstances. This led to the creation of a scenery based methodology (6) capable of comparing different modes under similar basis and where capital and operational costs are evaluated on a parametric basis.

A scenery is the characterisation of a urban corridor in terms of several variables that define the implementation and operational costs of any transport mode subject of the evaluation. The variables express the social and economical levels of the population living along the catchment area of the corridor, the demographic density, the topographic conditions, the demand for public transport, and the level of service to be achieved. The methodology was consolidated in a spreadsheet implemented on a microcomputer, the so-called AMT

2.0 system (7). The overall structure of the model is shown in figure 3.

The AMT 2.0 system requires the introduction of the characteristics of the vehicles, such as the internal layout, i.e. the number of seats and the area for standing passengers. The scenery is defined, amongst other input data, by the extension of the corridor, of straight and curve sections of the right-of-way, of power feeding lines, number of passenger stations and power substations. Demand related variables include the total average daily patronage, the percentage of the total occurring during peak and off-peak hours as well as the number of peak and off-peak hours. The user is also required to specify elements which relate the different modes to the specific scenery being evaluated, i.e. for each mode, the minimum and maximum operational headways during peak and off-peak periods and the journey speeds for the different periods of the day.

For each mode it is necessary to input the staff to operate and maintain the system either in terms of the size of the fleet or the number of stations. The model also requires the number of minimum wages paid to each category of personnel as, in many cases, drivers of different modes tend to earn different salaries.

In order to evaluate the total costs, the capital ones are converted to a time series so that they can be added to those arising from operating the transport system. The calculations require three different matrixes. One for the attractivity rates for each mode and equipment, capable of taking into account variabilities resulting from different economic policies. The second matrix specifies the useful life of each equipment of every mode and the third caters for the scrapping value of every major component of each mode. There is also scope for introducing the age of the components at the time of implementation; this is particularly useful for the cases arising from upgrading a mode such as the introduction of a bus lane over a corridor without acquiring new buses for the fleet. The AMT 2.0 system also needs the introduction of matrixes with the energy, annual maintenance and implementation costs. These costs are related to specific variables such as 'km of right-of-way' or 'vehicles'. Table 2 presents some of the values of the costs included in the evaluation; the size of the fleet and the total number of kilometres operated during the period of one year is calculated by specific modules of the spreadsheet. Table 2 includes information about articulated buses and trolleybus that were not included in the evaluation due to their difficulties to operate in narrow and congested streets of central areas; also the costs of constructing high-flow bus lanes are shown but not used in this particular scenery.

Figures 4 and 5 show sets of curves produced by the AMT 2.0 system. The scenery consists of a typical downtown circular line with a total extension of 3 km. The Aeromovel answer to this scenery would be a single elevated trackway, running either clock or anti-clockwise, with stops spaced every 300 metres. It is anticipated that the line will have some 25% of curves which cost 40% more than straight sections. Daily demand stands at 70000 passengers with 20% occurring during two peak hours. The Aeromovel (aero in the graphs of figures 4 and 5) is being compared to the following modes: mic (stands for microbus), bus (conventional bus), pad (new design for conventional buses) and trls (trolleybus). Maximum occupancy rates in the peak hours is considered as 7 standing passengers per square metre of floor area, which is reasonable due to the short trips and the small span of time spent inside the vehicles; the following vehicular capacities are reached: 35 passengers for a microbus, 76 for a bus, 109 for a Padron, 95 for a trolleybus and 300 for an Aeromovel. The average speed of the modes is assumed to vary between 8 and 15 km/h for the rubber-tyred modes operating at ground level during peak and off-peak periods respectively, and 20 to 32 km/h during the same periods for the Aeromovel travelling on an elevated and fully segregated trackway. Minimum headways are 5 seconds for road based vehicles and 120 seconds for the Aeromovel (90 seconds in the off-peak periods); the maximum headway allowed for all modes is 300 seconds. Scrapping value of all vehicles and equipment is taken as 10%. Useful life for concrete structures is 40 years, 7 years for rubber-tyred modes and 12 years for the Aeromovel.

Figure 4 shows the sensitivity of the costs per passenger, in American dollars, to the variation of the daily demand (100% is equivalent to 70000 passengers). All capital and operational costs are included. Figure 5 presents similar results, but now excluding the costs associated to the amortisation of the elevated trackway of the Aeromovel; amortisation is taken at the yearly rate of 12%. The reasons for excluding them are twofold:

i. the rubber-tyred modes running on the surface do not carry the burden of paying for the road space and traffic engineering measures they take and demand;

ii. the fact that Aeromovel is above the surface certainly improves the flow of pedestrians, commercial and other public and private forms of transport; the costs associated with this benefit should be charged to the community at large, rather than only to the Aeromovel passengers.

The results of the simulation run tend to qualify the Aeromovel as a promising alternative mode to tackle the public transport demand of such a circular line. The difference in shape between the curves of Aeromovel and the other surface modes results from the fact that maintenance and operational costs of the former are related to the infrastructure implemented, i.e. they are basically dependent on the extension of the trackway and the number of stations contrary to what happens with the other modes where they tend to be associated to the number of vehicles required to carry the different levels of demand. No scale-benefits are being considered for the rubber-tyred vehicles; investments required for building garages is directly proportional to the size of the fleet. Some discontinuity is also observed for the trolleybus as the substations for feeding the electric energy of the system are related to the frequency of vehicles that operate the line; at some demand levels more investments are required for the substations and lines and therefore average costs per passenger increase. Microbuses are found as expensive undertakings for the scenery as they require not only a larger fleet but also more drivers per passenger being transported than the other road-based modes.

It is easy to see in the case of the Aeromovel curves the moments where the AMT 2.0 system adopts a larger fleet, jumping from only 2 vehicles in operation to 3 and finally to 4 in order to cater for the total demand.

8. CONCLUSION

Governments of countries such as the USA, Germany, France and Japan tend to allocate a substantial amount of resources in research and development of innovative transport modes. They also support joint ventures between the private and the public sector in projects that contribute to improving mobility and accessibility levels within urban areas.

The potential market for non-conventional transport modes is likely to boom once the costs to implement and operate such systems can be substantially reduced. To qualify for being an effective member of the family of transport modes, a new system cannot only be technically and operationally sound; it must present performance indexes and costs which are competitive to the more conventional systems. Several new systems that satisfy the first condition have been proposed but only a few of them are capable of challenging the other modes in terms of costs.

The Aeromovel presents some characteristics which makes it different from other non-conventional modes operating on elevated trackways. Perhaps the key one is the use of non-motorised vehicles which are very light; construction costs associated to building the trackway are therefore quite low. A network of lines seems a better solution for tackling the public transport demand in dense urban areas; the metro alternative usually precludes heavy capital investment on a few lines capable of successfully attending, without mode-integration, only a limited number of corridors.

Studies to detect the potential market for the Aeromovel are being conducted. More results in terms of comparing the costs of this system to other modes have been presented elsewhere (8). Evidence depicted in figures 4 and 5 qualifies Aeromovel as a quite a promising alternative to cities considering the implementation of circular systems within downtown areas. Jackarta is probably the first city that will benefit from the implementation of a large network of Aeromovel. Technological development continues on the pilot line of Porto Alegre, Brazil.

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TABLE 1: General characteristics of urban transport modes

SYSTEM	LENGTH (m)	WIDTH (m)	PASSENGERS (seat+stand)	EMPTY WEIGHT (t)	WHEELS	WEIGHT/PLACE (kg/passenger)	SYSTEM/AEROMOVEL (ratio)
Atlanta Airport	11.9	2.8	16+128	12.5	rubber	87	3.0
Dallas Airport	6.7	2.2	16+44	6.35	rubber	106	3.7
Detroit	12.7	2.5	28+88	13.8	steel	119	4.1
Gatwick Airport	11.9	2.9	16+128	12.5	rubber	87	3.0
Lille VAL	26.0	2.1	44+232	29.6	rubber	107	3.7
Miami APM	11.9	2.8	16+128	12.5	rubber	87	3.0
Morgantown	4.7	2.0	8+13	3.97	rubber	189	6.5
DEMAG-MBB C Bahn	7.8	2.4	14+52	4.65	rubber	70	2.4
Fuji	8.8	2.3	24+72	10.5	rubber	109	3.8
Kawasaki	8.4	2.4	20+62	9.5	rubber	116	4.0
Kobe	8.0	2.3	20+62	10.5	rubber	128	4.4
Magnetbahn	11.6	2.4	26+88	7.5	magn.	66	2.3
Sao Paulo metro	21.7	3.2	66+306	30.0	steel	150	5.2
Aeromovel	25.0	2.8	48+252	8.7	steel	29	1.0

TABLE 2: Unitary costs of alternative modes (input for AMT 2.0)

****** COSTS OF IMPLEMENTATION PER UNIT US$ 1000 *****

DESCRIPTION	MICRO	CONV.	PADRON	ARTIC.	TROLL/S	TROLL/ART	AEROMOV.
ONE-WAY BUSLANE/km	500.0	500.0	500.0	500.0	500.0	500.0	
TWO-WAY BUSLANE/km	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	
SINGLE TRACK/km							1160.0
SINGLE CURVE TRACK/km							1380.0
SINGLE STATION							90.6
DOUBLE STATION							90.6
TERMINAL STATION							90.6
STATIONARY POWER ROOM							185.8
SIGNALLING/operated section							80.0
ONE-WAY OVERHEAD SUPPLY/km					53.6	53.6	
TWO-WAY OVERHEAD SUPPLY/km					81.7	81.7	
OVERHEAD POWER LINE/km					49.4	49.4	
UNDERGR. POWER LINE/km					217.7	217.7	
ONE-WAY SIDE WORK/km					85.0	85.0	
TWO-WAY SIDE WORK/km					85.0	85.0	
SUBSTATIONS					26.6	26.6	
GARAGES	1.4	2.7	4.3	8.8	19.8	25.1	20.0
VEHICLES	30.0	56.0	80.0	95.0	110.0	207.6	274.0

****** COSTS OF OPERATION PER UNIT US$ 1000 ******

--- MATERIALS AND MAINTENANCE SERVICE ---

DESCRIPTION	MICRO	CONV.	PADRON	ARTIC.	TROLL/S	TROLL/ART	AEROMOV.
ONE-WAY BUSLANE/km	7.6	7.6	7.6	7.6	7.6	7.6	
TWO-WAY BUSLANE/km	15.2	15.2	15.2	15.2	15.2	15.2	
SINGLE TRACK/km							12
SINGLE CURVE TRACK/km							14
SINGLE STATION							0.9
DOUBLE STATION							0.9
TERMINAL STATION							0.9
STATIONARY POWER ROOM							9.5
SIGNALLING/operated section							2.4
ONE-WAY OVERHEAD SUPPLY/km					1.5	1.5	
TWO-WAY OVERHEAD SUPPLY/km					2.3	2.3	
OVERHEAD POWER LINE/km					0.5	0.5	
UNDERGR. POWER LINE/km					2.1	2.1	
SUBSTATION					0.2	0.2	
VEHICLE/km	8.80E-05	1.18E-04	7.40E-05	8.00E-05	4.10E-05	6.00E-05	
VEHICLE					4.7	7.8	21

--- ENERGY ---

DESCRIPTION	MICRO	CONV.	PADRON	ARTIC.	TROLL/S	TROLL/ART	AEROMOV.
CONSUMED	8.40E-05	1.21E-04	1.54E-04	2.21E-04	1.60E-05	3.20E-05	1.23E-05
DEMANDED					1.2	1.8	7.7

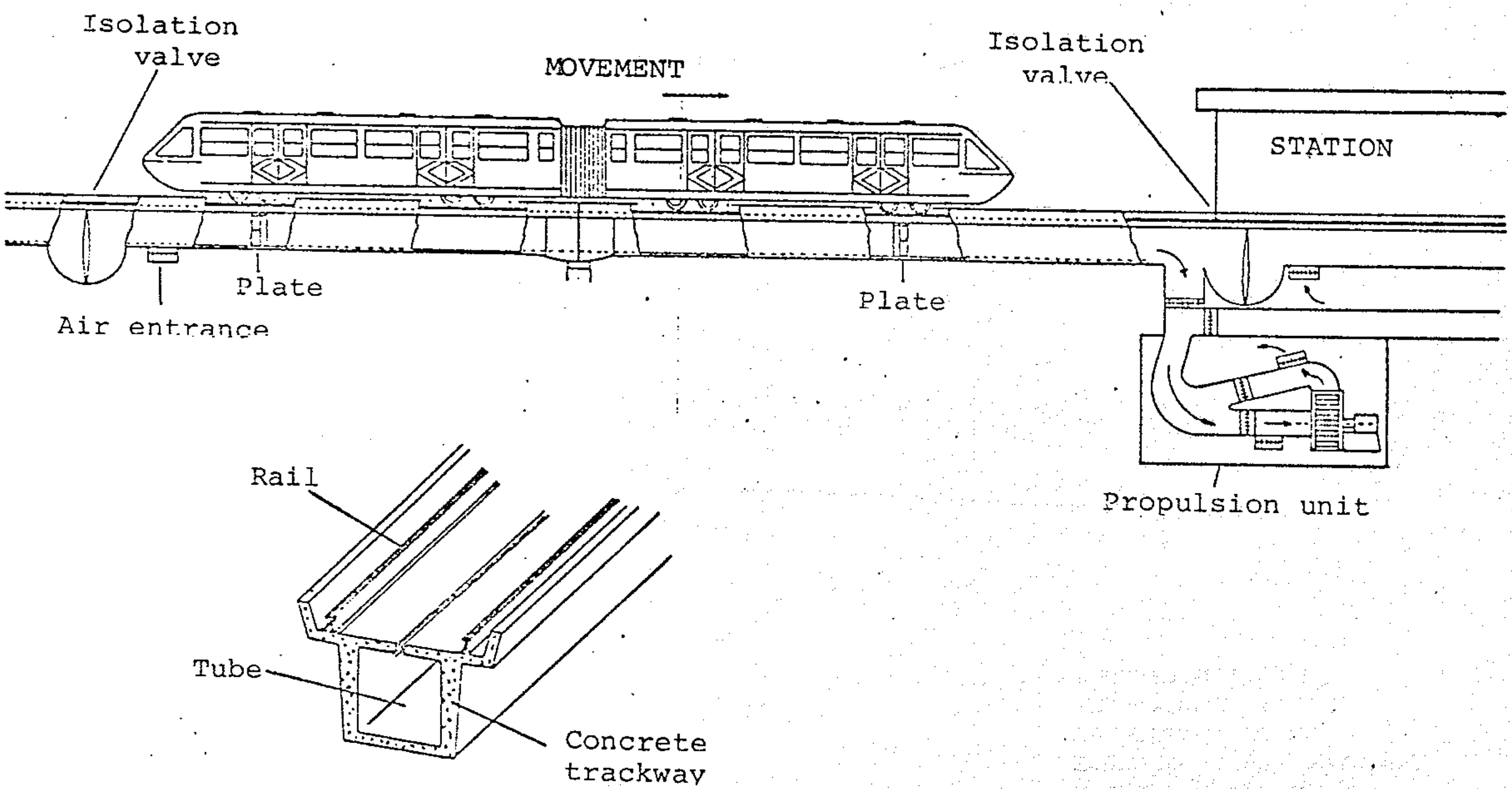

FIGURE 1: AEROMOVEL - key elements of the concept

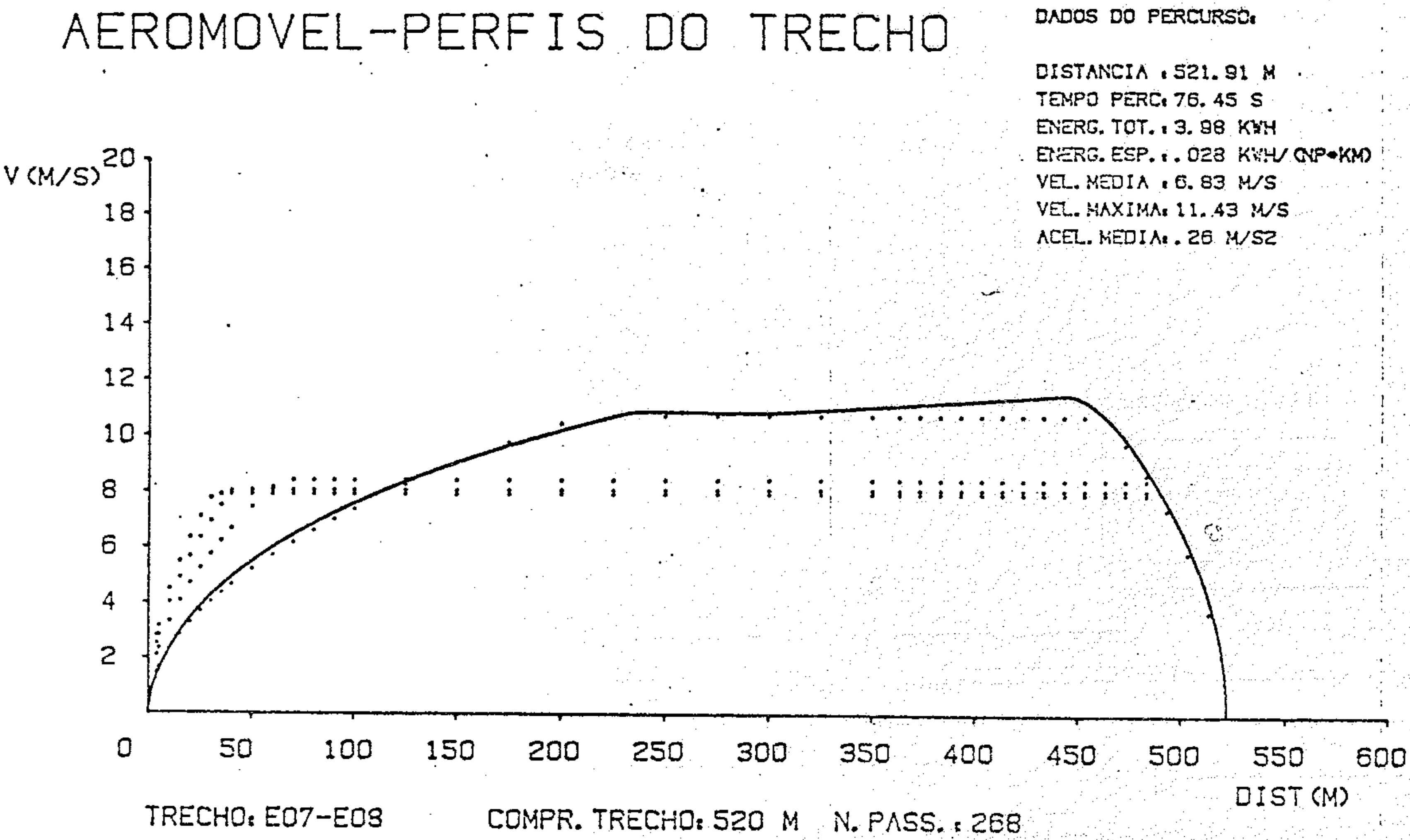

FIGURE 2: Simulating the operation between 2 stations

LINDAU

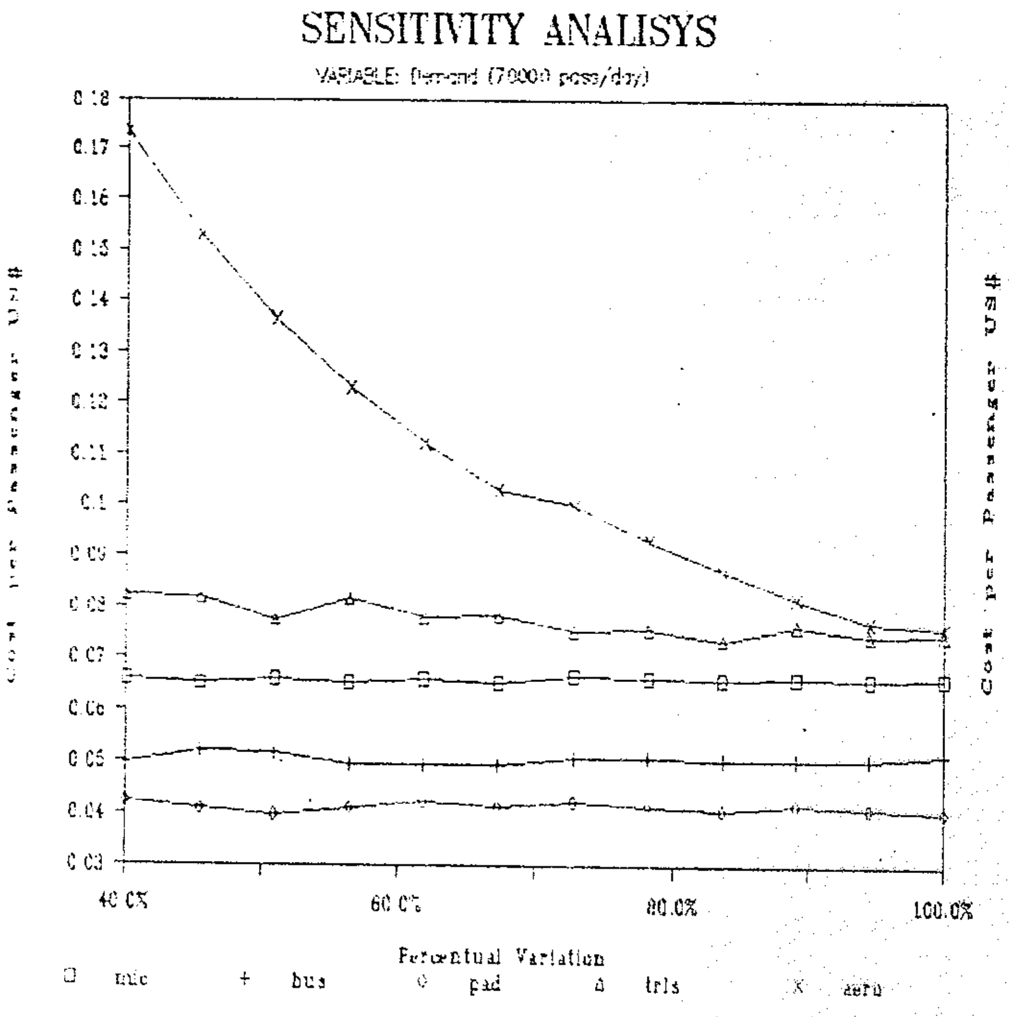

FIGURE 4: Alternative modes: total costs vs. demand

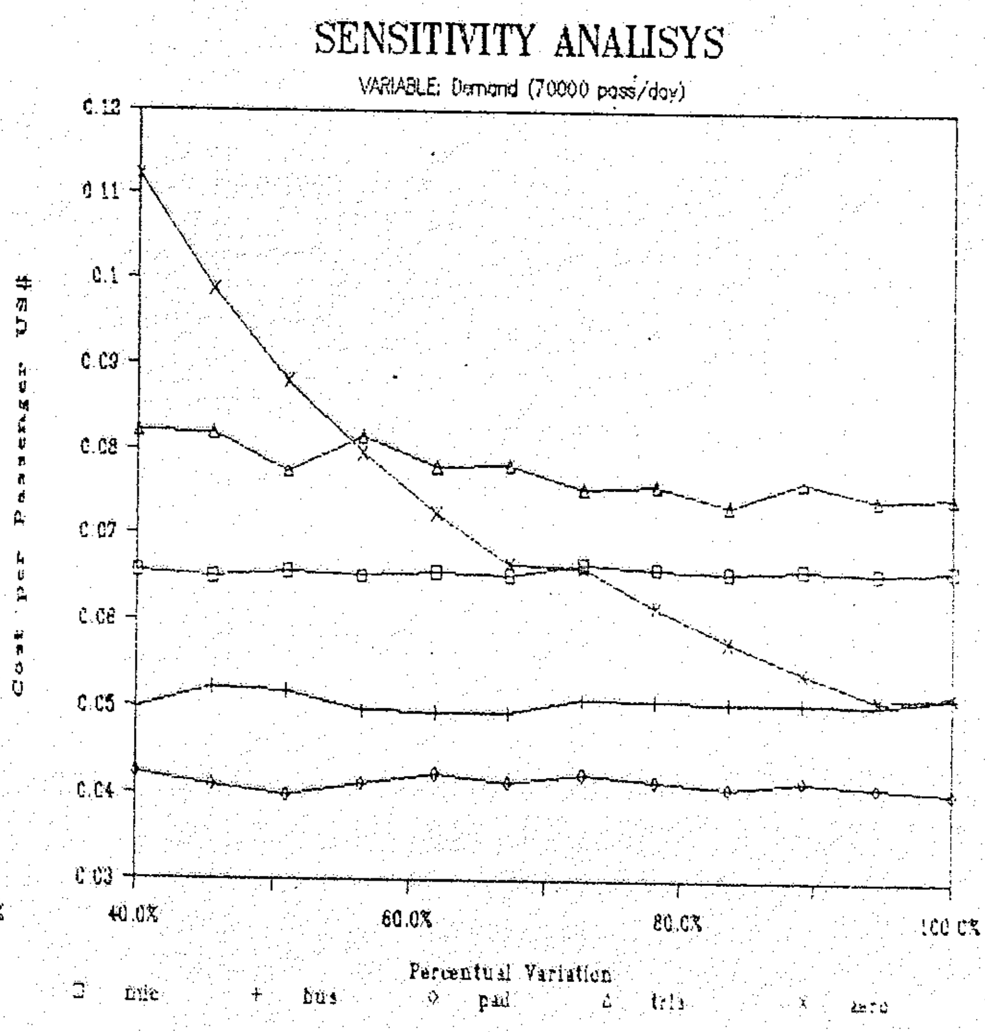

FIGURE 5: Alternative modes: costs (excl. amortis. for the Aerom.) vs. demand

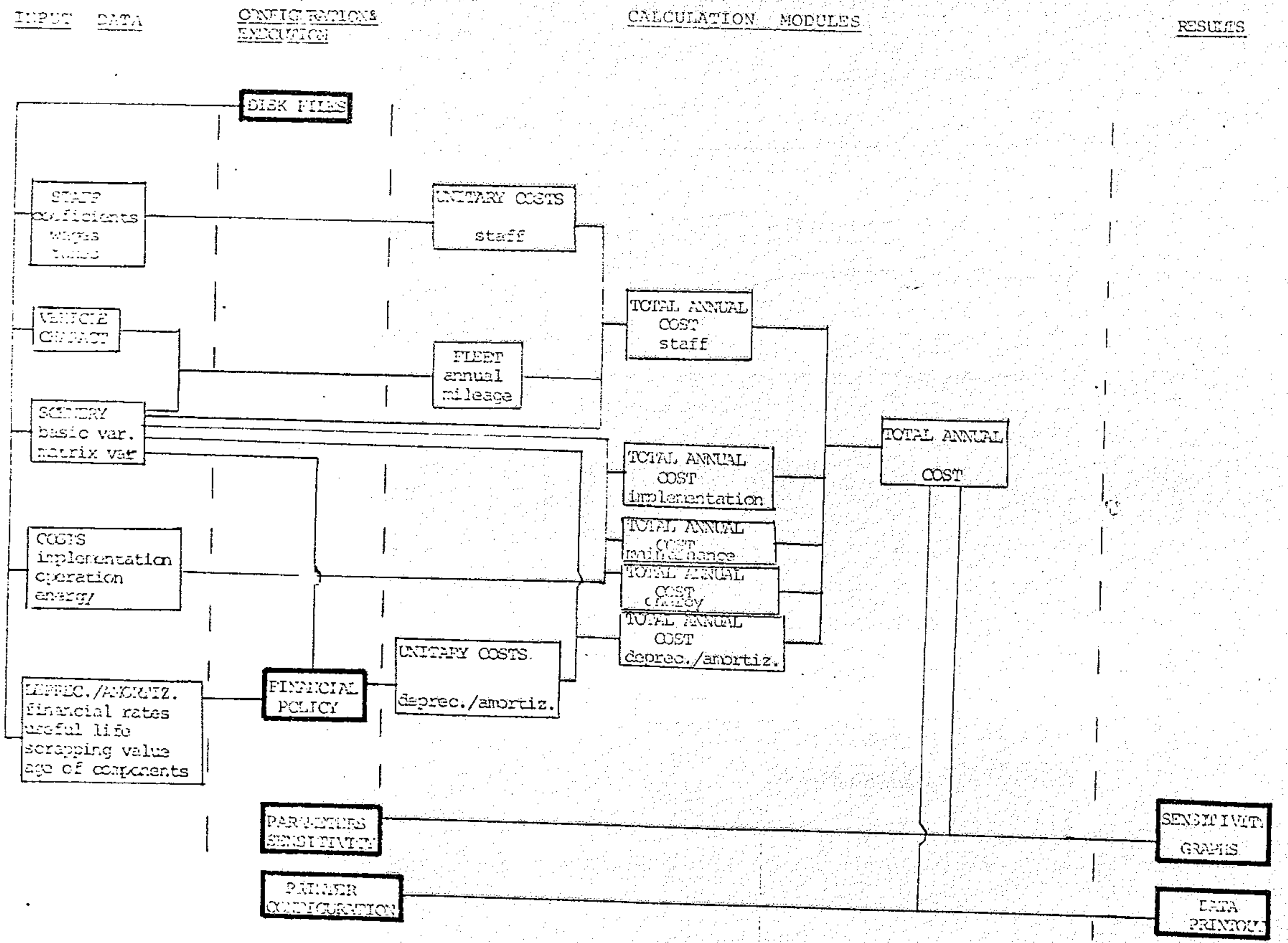

FIGURE 3: Structure of the AMT 2.0 system

1 MAJOR BREAKTHROUGH

The Aeromovel is a reliable, efficient and cost-effective innovation in passenger transportation that uses air propulsion for the movement of light weight, high volume vehicles.

Internationally patented by Coester Research, Ltd., of Brazil, the Aeromovel technology, using steel wheels and rails on an elavated guideway, is uniquely designed for safe, economical and environmentally compatible applications.

Aeromovel solves the problems of heavy weight vehicles usually used to carry light weight passenger loads on conventional rails or bus transit. With twice the capacity, but less weight than transit buses, and less than one-third the weight of light rail vehicles, Aeromovel carries 2 to 3 times more people per ton of deadweight than the next most efficient alternative! This high payload to weight ratio means thinner and less costly support structures, less wear and tear on guideway and vehicles, and less energy to move heavy equipment - resulting in more energy available for moving passengers.

Aeromovel achieves its ultralightweight by removing the power source from vehicles, and installing it in the guideway. The vehicle is driven by pressurized air against a rigid steel sail named propulsion plate, enclosed in a pneumatic duct beneath the tracks. The propulsion plate is attached to the bottom of the vehicle chassis and guided through the duct by a beam or mast named pylon, passing through a slit in the center of the tracks. The propulsion plate propels the vehicle forward or backward in response to air pressure created by blowers located strategically along the guideway.

Free of the weight of on-board motor, engine or transmission parts, the Aeromovel carrier benefits from all the advantages of steel rail operation with none of the drawbacks of heavy traction power. Steel wheels produce only one-tenth the resistance of rubber tires; steel rails combined with the enclosed steel propulsion plate and pylon provide a fail-safe guidance and anti-derailment feature. Aeromovel wheels do not provide traction, they act like simple ball bearings to guide, support and carry the vehicle over the track with very little wear or need for maintenance.

Stationary air blowers of rugged industrial design also require a minimum of maintenance; and because the propulsion mechanism is attached to the guideway, automation of this system is much easier to achieve than remote control of motors on independent vehicles of other people mover systems.

The advantages of Aeromovel result in extremely low cost installation, maintenance and operation, stemming from the system simplicity of engineering and its extremely high payload to weight ratio. This enables Aeromovel to be more capital efficient than any other system of people movers or conventional transit presently available.

Aeromovel guideways are normally elevated, and house the air duct, track, and the utilities. Grade separation permits the system to operate without interference from street traffic or others obstacles. Vehicle operation is controlled automatically by valves in the duct to regulate air flow based on information received from magnetic sensors located in the trackbed, and monitored by a central command post. Alternatively, operations at each station can manually control the air flow valves.

Because the energy requirements of air blowers for each route segment of Aeromovel can be addressed separately, power levels can be tailored for particular conditions such as gradients, passengers loads, and desired cruising speed. This avoids the heavy mechanical redundancy necessary on self-propelled vehicles to accommodate the most demanding power requirement of such variable route segment characteristics.

For rapid construction and minimum disruption to surrounding activities, the guideway is erected in prefabricated modular sections, usually prestressed concrete, which may be readily lifted into place by day or night.

In comparison with conventional fixed guideway transit, the Aeromovel system can be built and operated for a small fraction of their cost. Compared with other people mover technologies, aeromovel provides savings of fifty percent and more in total construction and operating costs per passenger.

Aeromovel provides efficient, effective passenger circulation in concentrade activity centers such as central business districts, major shopping centers and amusement parks. The system promotes frequent trips for diverse purposes in uncongested operation. By substituting for buses in mixed traffic, Aeromovel can achieve operating cost savings, improve the quality of service and eliminate pollution. In major development corridors where rail systems are feasible, Aeromovel high capacity lower capital and operating costs make it much more attractive than conventional fixed guideway transit. In conjunction with real estate developments and downtown revitalization, aeromovel offers exceptional return on investment and rapid installation in response to demand. Thus, Aeromovel is an excellent choice to enter the $4 to $6 billion U.S. people mover market expected to develop by 1990.

The basic Aeromovel propulsion and guideway systems also have potencial applications for commercial and industrial transportation including the movement of bulk goods and materials.

All of these advantages of Aeromovel including the benefits of clean, fast, efficient transportation and ease of integration with urban development have been demonstrated in Brazil, where technological growth and efficiency are the hallmarks of a rapidly expanding urban economy.

2 DESIGN FEATURES

Aeromovel transportation technology may be applied in urban transportation systems requiring passenger capacities that range from 5,000 to 30,000 passengers per hour per travel direction. Single vehicles carrying 120 to 240 passengers, and growth versions having up to four articulated cabins of that size, will handle the growing passenger demands found in urban mass transit.

Each vehicle is propelled by eletric-motor driven air blowers connected to a closed air duct beneath the track. The propulsion plate is attached to the vehicle truck, and guided through the duct as air flow propels the plate and vehicle. Independent control of air blowers permits varying speed zones along the route. Therefore the Aeromovel propulsion system contrasts favorably with much heavier, overly-sophisticated and costly eletric rotary motors, magnetic or linear induction devices of others people movers.

For maximum passenger convenience, Aeromovel stations may be spaced as required, with typical spacings less than one-half mile in major activity centers, and greater spacing in lenghty corridors. Air blowers are installed either inside the station structure (underneath the passenger platform), or in closed containers attached to the air duct where needed.

Aeromovel vehicles are passive operating units traveling on steel guide rails. Vehicle speed, acceleration and stopping are controlled by automatic regulation of air flow in the duct, through trackbed sensors and micro computers which govern air valves, or by manual operators at the stations. Hydraulic disc brakes are also installed on each vehicle for precision stopping. The enclosed propulsion plate attached underneath each vehicle provides a safety feature which prevents derailment.

The wheels, which are the only moving parts nevessary for the car operation - combined with the ultralight weight of vehicles ensure low noise, friction and vibration. Weight, noise and vibration characteristics therefore permit Aeromovel vehicles to operate inside buildings, much like a horizontal elevator.

The light weight of aeromovel vehicles not only ensures that energy is not wasted on moving heavy deadweight, but the extreme simplicity and high reliability of the Aeromovel system results in much less maintenance requirements than in any alternative people mover technology.

The unique operational advantages of the Aeromovel system include the following:

- Air propulsion eliminates the problems of heavy rail traction; wear on wheels and tracks is reduced to a minimum; acceleration and deceleration is smooth and efficient; vehicles climb steep grades; traction noise and vibration are eliminated.
- Motorization of Aeromovel by stationary air blowers permits optimum design of power plants in relation to specific requirements for each route segment. Major cost savings are obtained by appropriate sizing of air blowers for each route section.
- Capital and maintenance cost is low, due to simplicity of design and high reliability of air blowers. Rugged industrial blowers are used here to reduce the low air differencials required pressure on the steel propulsion plate, producing vehicle speed up to 50 mph (80 km/h).
- Air flow control valves are reliable, conventional valves used in time-tested industrial applications.
- Eletric motors on air blowers are sturdy, completely independent units. Because the purpose of these motors is to pump air, not drive the vehicle wheels, maintenance requirements are minimum. Even if one motor fails, others can continue to propel the vehicles.
- sensors, microprocessors and digital indicators used for control of vehicle operations are similar to eletronic equipment for naval and aircraft operation and control.
- air blowers are completely contained in sound-insulated housing units which reduce noise to negligible levels.
- Eletric lights, doors and climate control on the vehicles are operated by independent 12-volt dc batteries on board, fed by safe low 55 volt ac eletric current through the rails.
- Prefabricated columns and guideway structure permit rapid installation and easy bridging of streets below, to provide congestion-free operation of vehicles.

3 PROPULSION SYSTEM

Aeromovel is driven by a pneumatic propulsion system which efficiently transforms electrical energy to air flow and transmits thrust directly to the vehicle without gears, power train or intervening electrical circuits. Commom centrifugal blowers with airfoil blades are attached to the guideway duct beneath the guideway in order to produce air circulation. Air can be exhausted from the duct into the atmosphere, or forced into the duct through a ventilator at the blower location, providing thrust in either direction as required in a typical application. The blowers produce air flow of 50,000 cubic feet per minute and static air pressure of 2 lbs/in2 inside the duct which acts directly upon the steel sail mounted beneath each vehicle. In this example, as the vehicle accelerates, the effect of the blower varies according to the performance curve of pressure vs. air flow exhibited in figure 1. From a complete stop, the air blower delivers substantially constant thrust to the vehicle up to 25 MPH. Thereafter, thrust and acceleration decrease until air flow and vehicle speed achieve normal cruising velocity of 40 MPH. Additional power can be obtained from a combination of "Push" and "Pull" by two successive air blowers. The top part of the graph shows power requirements of a single air blower corresponding to vehicle speed and air flow, expressed in horsepower.

Normal vehicle stopping is produced by a combination of reverse air thrust in the pneumatic duct and hydraulic disc brakes on board the vehicles. Either system alone can stop the vehicles. Emergency stopping is produced by shutting down the air duct; stopped air flow creates a blocked "tire pump" effect that halts vehicles rapidly. For added safety, a compressed column of air between the propulsion plate of two vehicles in the duct prevents one vehicle from entering the route segment of another.

Normal vehicle acceleration and decelaration are very smooth and efficient, with no discernible jerk. Aeromovel vehicles can climb steep grades, due to its unique traction. Traction noise and vibration are eliminated by this smooth and quiet form of propulsion. The air blowers are contained in sound-proof housing units, which reduce noise to negligible levels, less than the background noise of city streets.

The air blowers and ventilators used by Aeromovel are standard industrial equipment commonly used for large ventilation systems. Excellent system reliability is achieved by using these sturdy industrial components. The cost to purchase air blowers is much less than the cost of commercial propulsion motors or engines; and the maintenance cost of these rugged stationary devices is very low, because of their simple design and operation. The mean time between air blower failures is 100,000 hours.

Air blowers are completely independent. Even if one fails, other air blowers will continue to propel the vehicles. Because the function of these brushless eletric motors is to pump air, not drive the vehicle wheels, their only periodic maintenance need is to replace motor bearing - every ten years.

Since electrical transmission is not used in this passive propulsion system, exposed high voltage has been eliminated, an added safety feature.

4 VEHICLES

Aeromovel vehicles are aeronautically designed with integrated light weight structural frame and shell, supported by hardened steel wheels on conventional rails. Wheels tum freely, without the need for differential, allowing 50 feet minimum timing radius. The steel propulsion plate suspended beneath each vehicle is structurally attached to its truck by a steel pylon. The vehicle suspension system consists of pneumatic air bags with automatic pressure and weight distribution.

Eletric lights, pneumatic doors and climate control on the vehicles are opened by two independent 12-volt dc batteries on board, fed by low 55-volt ac eletric current through the rails. Front and rear windows of the vehicle provide emergency exits.

The hydraulic brakes act on all wheels, automatically controlled by an anti-skid system. Reverse pressurization in the duct is controlled by a microprocessor, which also remotely activates the brakes to stop vehicles at stations within 20 inches of their target. Once stopped, differential air pressure in the duct is reduced to zero, and the brakes immobilize the vehicle during the time at the station.

The extreme light weight of Aeromovel vehicles, coupled with low vibration and friction on the wheels produces very low noise levels. The only sound generated by the vehicles is from the smooth contact of the wheels as they roll on the track.

5 SUPPORT AND GUIDEWAY

The fixed guideway of Aeromovel consists of a pre-fabricated prestessed concrete, box beam, which supports the track and vehicles, and trhough which air circulates. The cross section in a typical application of the air duct is approximately 11 ft2. Guideway sections come in lenghts of 75 to 100 feet, supported on thin precast columns, which permit easy bridging of streets below to avoid conflicts with traffic. Columns footing and profiles are designed to suit local site conditions. Steel rails are mounted on top of the air duct to guide vehicles in congestion-free exclusive operation.

A three inch wide slit extends along the top of the air duct between the rails to allow passage of the pylon connecting the steel propulsion plate to the vehicle. A flexible rubber gasket is attached to each side of the slit which permits passage of the pylon and provides air sealing for the duct. This seal lasts 10 years and is easily replaceable.

Aeromovel switching is similar to conventional railway track switching, with added provision for diverting the air flow and propulsion plate. A moving track section clears the rails and guides slit to permit the passage of vehicle and pylon. Two valves under the track alternately close the section of air duct out of use.

Aeromovel stations are constructed adjacent to the guideway with level-entry platforms for ease of passenger entry and exit from vehicles. stations may be spaced at any distance desired. Provisions for passenger waiting areas, elevators, escalators, operator control booth and power plant are integrated with station design as needed.

Modular construction of the Aeromovel guideway system permits assembly-line manufacture of beams at a remote site and rapid erection with several sections lifted into place per day.

6 CONTROL AND AUTOMATION

Aeromovel vehicle control is achieved by regulation of air flow valves at the air blowers, and section isolation valves in the air duct. A route segment between two isolation valves is for the exclusive operation of one vehicle, similar to railway block control, providing absolute collision prevention. Air flow valves on the intake and exhaust manifolds of air blowers produce air pressure, vehicle acceleration and decelaration in each route segment. Louvers on the air flow valves may take several open angular positions, thereby providing variable air flow control.

Valves in each route segment are regulated individually by electrical signals from section control units located at passenger stations, and monitored by the central command post. Magnetic sensors in the trackbed transmit information on the position and velocity of vehicle to the section control unit. In automated operation, a microprocessor computes the necessary information and commands the valves to produce preprogramed air pressure and direction of air flow. For added safety, the vehicle brakes are activated automatically when passsing station warning sensors. If electrical power fails, the valves are weighted to shut down automatically and block further air flow, thus stopping vehicles quickly.

Alternatively valves may be controlled by manual operators in control booths at passenger stations. A visual display on the operator´s panel indicates the position of all valves. Digital indicator exhibit the speed of vehicles in each route segment, based on information from trackbed sensors. Vehicle location on route is also exhibited in a luminous display at each section control booth, and - along with all other information from the section control units - at the central command post for systemwide control. Even in manual operation, Aeromovel requires no driver on board the vehicles.

Eletric solid state sensors, microprocessors and digital indicators for regulation of the air valves are similar to electronic equipment used for naval and aircraft operatrion and control. Air blower valves used to control Aeromovel vehicles are reliable industrial parts commonly used in pneumatic applications. Because Aeromovel propulsion equipment is attached to the guideway, automation is much easier to achieve and even more dependable than for other people mover systems.

When an Aeromovel vehicle leaves the station, valves on the next air blower are opened, and air is expelled from the duct into the atmosphere. When cruising speed is attained, the valve is modulate in a partially closed position limiting power for the desired speed.

For deceleration, the control valve is fully closed. The vehicle slows due to air being compresses in fornt of the steel propulsion plate. If required, reverse thrust may be applied by reversing the air flow in front of the vehicle. Magnetic induction coils on the trackway activate the vehicle brakes to supplement the stopping action. Once stopped, the hydraulic brakes lock, holding the vehicle at the station during passenger boarding operations.

When the air blower valve is fully closed, the main duct is isolated from the blower, and remains at zero pressure differential and air flow. In this condition, the blower idles, and no air is pulled through the mainfold. Energy consumption is at a minimum.

Valves in the air duct separate one route section from another. Vehicles enter a route segment only when the vehicle ahead has already entered the next section. With reduced headway operation, each station is isolated in a separate section. In this case, a vehicle may enter a route segment right after the vehicle ahead has entered the next station.

In a typical urban transportation system, spacing between stations is approximately one-quarter to one-half mile. The Aeromovel system permits optmum propulsion power for each route segment, taking into consideration the following factors:

- Distance between stops;
- Desirable cruising speed;
- Grade of incline;
- Traveling time for each section.

The necessary vehicle accelaration and average speed are calculated. Based on this information, the requires air flow and static pressure produced by each air blower can be determined. Major cost savings are obtained by the appropriate sizing of air blowers for each route segment. This is an exclusive efficiency advantage of the Aeromovel transportation system.