Rubric 1 . TECHNOLOGIES AND PROJECTS

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AIR CUSHION VEHICLE (ACV): HISTORY DEVELOPMENT AND MAGLEV COMPARISON

Abstract. This paper will present the ACV working principle and a review of the past research developments of high-speed ACV trains and their efforts in countries like, Brazil, France, Germany, Italy, United Kingdom, and United States, and the low-speed ACV trains, revealing why the former did not match the expectations and failed, while the latter have been prospered and purchase a well-established market niche in short distance paths.
Finally, this study will promote a direct comparison between the two technologies, ACV and MagLev, with advantages and disadvantages of each one. The ACV development will bring important insights to the research of MagLev trains from a technical and economic perspective, learning with errors of the ACV, that did not enable any high-speed projects to flourish, and, on other hand, the comparative success of the urban ACV, as a complete commercial solution, like the MagLev trains.

Keywords: Air Cushion Vehicle, Tracked Air Cushion Vehicle, Hovertrain, Magnetic Levitation Train, High Speed Transportation, Urban Transportation.

List of Abbreviatures:

ACV	Air Cushion Vehicle
APM	Automatic People Mover
DoT	U.S. Department of Transportation
EDL	Eletrodynamic Levitation
EESC USP	*Escola de Engenharia de São Carlos da Universidade de São Paulo*
EML	Electromagnetic Levitation
FEI	*Centro Universitário da Fundação Educacional Inaciana*
Fultrace®	Fast Ultra-Light Tracked Air Cushion Equipment
HSST	High Speed Surface Transport
HST	High Speed Train
IAP	*Istituto d'Aeronautica dell'Universitá di Palermo*
LEM	Linear Electric Motor
LIM	Linear Induction Motor
LIMRV	Linear Induction Motor Research Vehicle
LRV	Light Rail Vehicle
LSM	Linear Synchronous Motor
MagLev	Magnetic Levitation
OHSGT	Office of High Speed Ground Transportation
PRT	Personal Rapid Transit
PTACV	Prototype Tracked Air Cushion Vehicle
RTV	Research Test Vehicle

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SML	Superconducting Magnetic Levitation
TACV	Tracked Air Cushion Vehicle
TACRV	Tracked Air Cushion Research Vehicle
TALAV	*Trem Aerodinâmico Leve de Alta Velocidade*
TLRV	Tracked Levitated Research Vehicle
TR	*Transrapid*
TTC	Transportation Technology Center
TTI	Transportation Technology Inc.
UK	United Kingdom
USA	United States of America
UTACV	Urban Tracked Air Cushion Vehicle
U-Trace®	Urban Tracked Air Cushion Equipment

INTRODUCTION

For almost two decades of the 20th century, between 1950 and 1970, the world witnessed a huge period of economic growth and global prosperity. This era faced a massive shift of population from rural areas to cities, forming large metropolitan areas. The industrial production reached even more people, demanding transportation of goods for far distances and the increasing of a consumer society [1, 2].

The "American Way of Life" promoting the ownership of automobiles, associated with the United States of America (USA) government impulse on the built of a national highway network [3], provided a boost in the car sales causing, quickly, traffic congestion and pollution problems [4]. The environmental concerns in these years were manifested at the first United Nations Conference on the Human Environment (1972) [5].

At the rail sector, this period presented new challenges and significant changes. Japan opened the first high speed line, the *Tokaido Shinkansen*, for the 1964 Summer Olympics in Tokyo, connecting the capital to Osaka [6]. European countries started the improvement of their rail network infrastructure, for passenger and freight transportation, and begun the studies for high speed lines [7, 8]. The USA government encouraged the research and new enterprises for urban [9] and for high speed transportation [10].

These decades witnessed an extraordinary advance on science & technology. The recently developed transistors opened new opportunities for light and compact products, like the pocket radio, and aided the growth of microelectronics, while the thyristors paved the way for the beginning of power electronics. The increasing of signal processing capabilities and the manufacturing of reliable sensors also contributed to surging of highly sophisticated systems, like artificial satellites.

At the same period, the British engineer Sir Cristopher Cockerell designed the *Hovercraft*, a hybrid vehicle that could be used over land or water that floats

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over the surface, using air pressure streams [11], while the British engineer Eric Laithwaite developed the first operational linear electric motor [12].

This scenario of economic, social and environmental modification, together with the enabling technologies contributed to the forthcoming of new modes of transportation, that were presented as the solution for urban mobility or for long distance travel concerns [13]. These fruitful era for innovations on this subject, which was best represented with the U.S. International Transportation Exposition of 1972 (Transpo'72) [14], saw the emergence of two nonconventional technologies: the air-cushion vehicle (ACV) and the magnetic levitation (MagLev) trains.

This paper will present the ACV working principle and a review of the past research developments of high-speed ACV trains and their efforts in countries like, Brazil (TALAV), France (*Aérotrain*), Germany (*Transrapid* TR-03), Italy (*Aerotreno*), United Kingdom (Tracked Hovercraft), and United States (TACV), and the urban ACV trains, revealing why the former did not match the expectations and failed, while the latter have been prospered and purchase a well-established market niche of automated people movers (APM) in short distance paths like airport terminals, resorts, and campus or hospital buildings, reaching currently nine commercial lines spread across the world.

Finally, this study will promote a direct comparison between the two technologies, ACV and MagLev, with advantages and disadvantages of each one. The ACV development will bring important insights to the research of MagLev trains from a technical and economic perspective, learning with errors of the ACV, that did not enable any high-speed projects to flourish, and, on other hand, the comparative success of the urban ACV, as a complete commercial solution, like the MagLev trains.

AIR CUSHION PRINCIPLE AND APPLICATIONS

The air cushion suspension working principle is based on the pressure difference of air streams external and internal on an air chamber that produce a mechanical force strong enough to float an object some millimeters above the ground, like a vehicle.

Fig. 1 presents a simplified picture of the air cushion working principle, as experienced on a hovercraft. A fan pulls the air streams, represented in red, to fill the air chambers placed inside the vehicle, producing high pressure streams, that inflate them until their allowed limits, which generate an upward force that lifts the vehicle above the surface with a small airgap. The skirt, in green, is a made of a flexible material that lets escape only few airstreams [15]. The air cushion mathematical formulation is elegantly described in [16].

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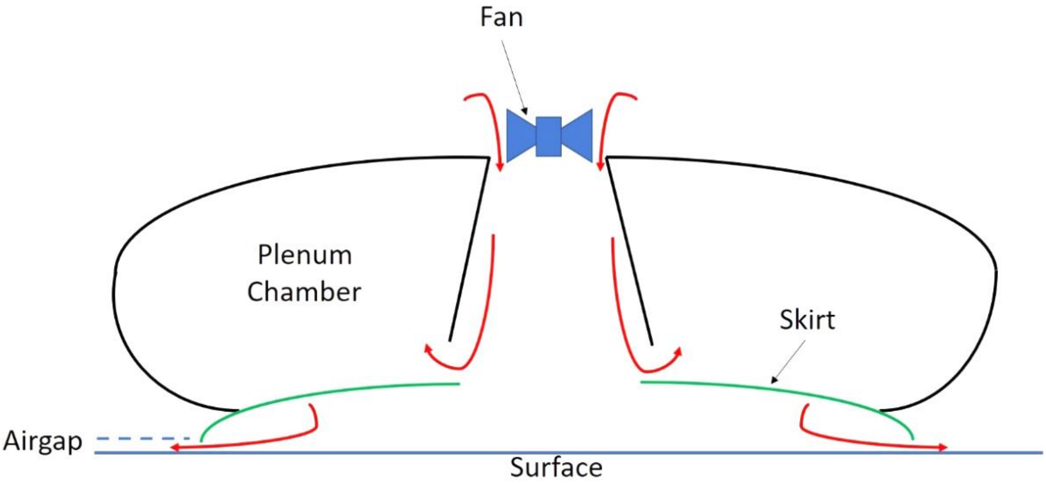

Fig. 1. Air cushion principle on a hovercraft

The air cushion suspension working principle together with the availability of reliable materials found several applications in different areas, like in the medical treatment of burned people, relieving the patient's pain and avoiding him touch the bed [17], and on the consumer goods segments, like vacuum cleaners [18] and lawn mowers [19], that take advantage of their own centrifugal fan to direct the airstreams to the bottom of the product and provide a less difficult job to users.

On the transportation sector, the air cushion suspension was exploited because of its drag reduction and the capability to move large amount of goods and people in a variety of terrains, like land, water, snow, swamp and sand, attracting the attention of military and rescue applications, and for maritime displacement on hovercrafts, with large success in the United Kingdom [20]. This technique inspired its use also for vehicles over land, like automobiles [21], for its futuristic appeal, and trucks for agricultural purposes [22].

AIR CUSHION IN HOVERTRAINS

The success of the ACV technology for maritime hovercrafts, the development of the linear electric machines (LEM) and the search for new modes of mass transportation induced this suspension principle to be applied, with some adaptations, at ground transportation, notably in guided systems like trains, producing the hovertrains or tracked air cushion vehicles (TACV).

Fig. 2 presents a schematic picture of one conventional hovertrain. The suspension air pad pumps the air to inside of a chamber and provides a pressure difference that produces a mechanical force that floats the vehicle, while the guidance air pads, placed at left and right of the vehicle, avoid any lateral contact with the support beam. The interaction between the primary and secondary windings of the linear motor is responsible for the vehicle propulsion [23, 24].

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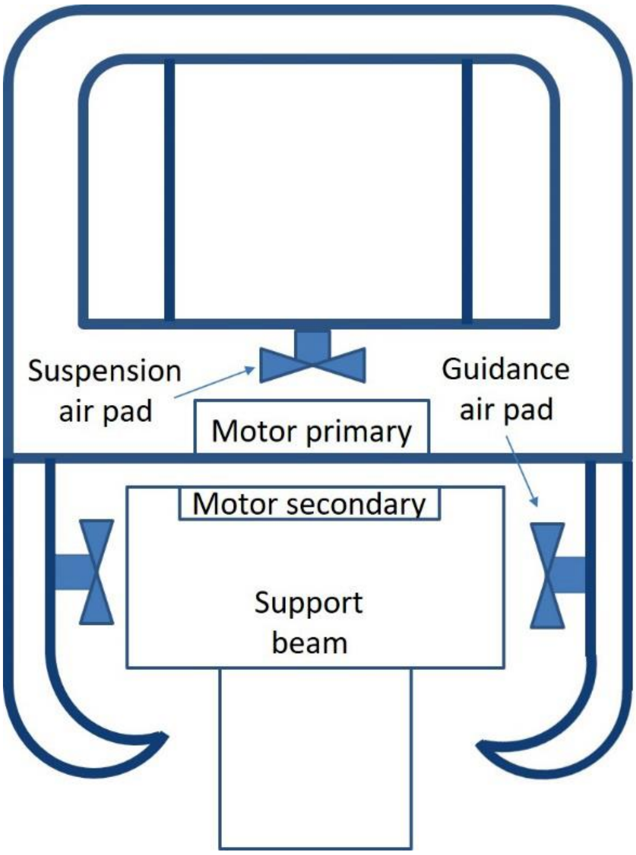

Fig. 2. Cross-section diagram of a conventional hovertrain

This section will present a review of the past research and development of high speed and urban hovertrains in several countries, with technical information of each one and their outcomes [24, 25].

I. High Speed TACV

A. United Kingdom

The great expertise obtained with the hovercraft development was one of the factors that made the United Kingdom to be one of the countries that lead the hovertrains research [26].

The Tracked Hovercraft project was started in 1962 with studies about the track's surface and its interaction with the cushion principle, by air or gas, that showed the technical feasibility of this technique with a prototype in 1963. A small-scale model was built and demonstrated, in 1966, on a closed loop that provided the linear inductor motor (LIM) propulsion [27, 28].

From 1971 to 1973, a 1.6 km of the planned 32 km test line, with an inverted T shape, was built and a full-scaled model, named RTV 31, was designed with a single sided LIM. The vehicle reached a maximum velocity of 170 km/h and the project was abandoned in 1973 by lack of funding [29]. The RTV 31 mock-up is illustrated in Fig. 3.

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Fig. 3. RTV 31 mock-up at Railworld Wildlife Haven Museum
(Source: Wikimedia, Public Domain)

B. *France*

The French interest on TACV begun in 1956, with the studies of the air cushion technology. After the demonstration feasibility of small scale models, the half scale prototypes, *Aérotrain* 01 and 02, were tested on an inverted T shape track of 6.7 km length in 1965, with different propulsion methods, like propellers, turbo fans, jet fans and rockets, reaching a maximum velocity of 345 km/h with the latter and 422 km/h with the former [30, 31].

In 1969, the real scale vehicle *Aérotrain* S44 was developed to inter-city transportation and designed with LIM propulsion of double-sided type, obtaining a maximum velocity of 200 km/h on a 3 km test track. At the same year, an 18 km test track was built to the vehicles *Aérotrain* I80 and I80-HV, both designed for 80 passengers, with turbo fan propulsion reaching a maximum velocity of 430 km/h. The *Aérotrain* research was finished in 1977 due to lack of financial support [32].

C. Italy

In 1967, the Aeronautics Engineering Institute of Palermo University started the research of TACV with a small-scaled prototype, the *Aerotreno* IAP-1, to prove the technical feasibility.

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The prototype IAP-2 was designed for three passengers, with a turbo-propeller propulsion and was verified on a 200 m track at the university campus. In 1972, the vehicle IAP-3, with seating capacity of 20 passengers and LIM propulsion, was tested on a 600 m track, of U shape, at the Trapani-Milo Airport. The IAP-3 designed velocity was 250 km/h. In 1973, the university moved their research focus to magnetic levitation trains [33, 34].

D. Germany

During the beginning of the MagLev trains research, West Germany developed the prototype Transrapid 03 (TR-03) based on air cushion levitation in 1972. The purpose of this study was to perform a direct comparison between a TACV and a MagLev EML vehicle, the Transrapid 02 (TR-02), at the same conditions and on the same track [35, 36].

The TR-03 and TR-02 were tested on a 930 m track, both with double-sided LIM propulsion. While the latter reached a maximum velocity of 164 km/h, the former obtained 140 km/h and it was considered with a lower performance than TR-02. The tests were conducted until 1974 when the research proceeded focused on MagLev trains only [37, 38].

E. United States of America

The TACV research in the USA was benefited by the governments' stimulus to high speed transportation systems, since 1965 [10]. In 1969, the U.S. Department of Transportation (DoT), by its OHSGT, begun the construction of a large complex (TTC), located at Pueblo, Colorado, devoted to the study of urban trains and HST and opened the program named Tracked Air Cushion Vehicle [39].

The first prototype, LIMRV, manufactured by Garrett Corporation Air Research Manufacturing Division, was focused only on the vehicle propulsion by LIM or jet engines, running on a wheel-rail system in a 10 km test track with inverted T shape. At the same time, in California, the vehicle TLRV with ACV suspension system, made by the same company, was designed to analyze the power collection to the LIM primary at speeds of 480 km/h [39, 40].

In 1972, the prototype TACRV, manufactured by Grumman Aerospace Corporation, was tested in 35 km track and reached 150 km/h with propulsion provided by jet engine [41, 42]. Figure 4 shows the TACRV mock-up. In 1974, the Rohr Industries started the PTACV program that designed the vehicle UTACV with a seating capacity of 60 passengers and double-sided LIM propulsion, very similar to the *Aérotrain* technology, and oriented to the inter-city transportation. The UTACV reached 240 km/h on a 5 km test track [43].

The USA TACV program was finished in 1975 due to lack of financial support, that was targeted to research of the magnetic levitation trains and to the development of automatic people movers (APM) to urban transportation.

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Fig. 4. TACRV mock-up
(Source: Wikimedia, Public Domain)

F. Brazil

In 1970, the *Centro Universitário* FEI, in São Bernardo do Campo, São Paulo, started a tracked air cushion high speed program, named TALAV, taking advantage of the institution’s large expertise acquired at automotive industry, and employing only Brazilian technology and materials.

The first step of the research was the study of small scale prototype to prove the technical feasibility of the ACV suspension and the propulsion system by propellers or jet engines. In 1972, it was developed a real scale vehicle, designed with a seating capacity for 20 passengers, and a propulsion by two jet engines, that would reach a cruise speed of 200 km/h. Fig. 5 shows the TALAV vehicle where it was displayed at the Brazil Export Exposition, in São Paulo, at the same year.

Its most remarkable characteristics were its very light structure, manufactured with fiberglass and aluminum sheets; a mechanism to facilitate the guideway switching; a telescoping door, designed to minimize stations dimensions and to help the passengers exit in case of an emergency; and the capacity to easily exchange the cabin between freight or people’s transportation when it was desired, and to connect wagons like building blocks according to demand.

Despite the success at the exhibition and some Brazilian cities proposals, the test track was never built due to government budget restrictions, and the research was finished in 1973 [44].

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Fig. 5. TALAV vehicle at the Brazil Export Exposition
(Courtesy from *Centro Universitário* FEI)

The Table 1 summarizes the technical data of different high speed TACV prototypes from the six countries above.

Table 1. Technical data of high speed TACV prototypes

Vehicle	**RTV 31**	***Aérotrain* 01**	**IAP-3**	**TR-03**	**UTACV**	**TALAV**
Country	UK	France	Italy	Germany	USA	Brazil
Vehicle length (m)	22	10	13	12	28.6	15.6
Seating capacity	–	6*	20	4*	60	20
Overall weight (t)	23	2.5	10	8	21	3
Maximum Speed (km/h)	173	345	N/A	140	240	–
Designed Speed (km/h)	480	N/A	250	N/A	274	200
Fan power (kW)	~630	75	N/A	~160	520	44.7
Propulsion	SS LIM	Propeller/ rocket	DS LIM	DS LIM	DS LIM	Jet engine
Motor Power (kW) **Thrust (kN)**	3730	185 11.8	450	 24.5	2000	 9.4
Guideway track length (m)	1.6	6.7	0.6	0.96	5	–

Note: * = crew members only. N/A = data not available. ~ = approximately.
DS = Doubled sided LIM. SS = Single sided LIM.

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G. Other High Speed TACV programs

During the 1960s and 1970s, the high speed TACV attracted the interest from companies and universities that developed studies, like the Tracked Air-Cushion Research Vehicle of the General Electric Co., with LIM or jet engines propulsion, and the non-evacuated tube system Tubeflight, proposed by the Rensselaer Polytechnic Institute [40, 45].

In 2013, a French Brazilian partnership, from the TACV Engineering France and the Aeronautics Engineering Department (EESC) of the *Universidade de São Paulo* (USP), emerged with the Fultrace® Project intended to resume the previous *Aérotrain* concept, and to obtain a speed range between 250 km/h and 400 km/h. This program still plans an Urban or Suburban version, the U-Trace®, designed for speeds of 100 km/h [46].

II. Urban TACV

In Lyon, France, an urban hovertrain was designed to transport passengers on a monorail system. The URBA project started the construction of a 4 km test track, in 1968, to study two prototypes: URBA 4 and URBA 8, with seating capacity of 4 and 8 passengers, respectively, and a speed of 55 km/h. As it was a suspended monorail, the vehicle moved below the guideway causing a modification in the air cushion mechanism. In this situation, the cushion system sucks the air producing a negative pressure difference that suspends the vehicle. This transportation system intended to manufacture vehicles to 30 (URBA 30) or 100 passengers (URBA 100) and LIM propulsion [47, 48].

In the 1960s and 1970s, there was a big interest in the development of automated people movers (APM) systems, where small computerized vehicles move on pre-defined routes [49]. This movement was stimulated, particularly, in the USA with the government incentives to new rail urban transportation and environmentally friendly systems, since 1964 [9].

In this sector, the personal rapid transit (PRT) system appeared as a solution to displacement of people in small cabins designed for few passengers. This means of transport is suitable for small routes, like airport or hospital links, university campus and tourist locations. In 1967, the PRT Uniflo was presented as an automated system for 8 passengers with suspension and propulsion provided by air that circulates on a duct of the guideway [13, 50].

The Otis Hovair® technology, developed by Transportation Technology Inc. (TTI), from General Motors, and subsequently incorporated by Otis Elevator Company, is a PRT system designed with the TACV levitation and with LIM propulsion that made its first appearance at the Transpo'72, in Washington D.C., and was followed by the construction of a test track, in Denver, Colorado. The air cushion system presented rubber pads below the vehicle that enable the air circulation on a quieter manner. Although the initial planning, all the commercial versions of the Otis Hovair® were available with propulsion by cable-hauled driven, considered as a horizontal elevator [13, 51].

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The first Otis Hovair® train was built in 1979, at the Duke University, and was designed for patient's transportation between different medical centers inside the campus with a track length of 400 m. This was the only vehicle with LIM propulsion and its operation remained until 2008 [52]. Figure 6 shows the PRT at Duke University.

Fig. 6. Otis Hovair PRT at Duke University Medical Center
(Source: Wikimedia, CC BY-SA 4.0)

From 1985 to 1999, the Otis Hovair® system moved passengers from Harbour Island to Downton Tampa, in Florida, on a 760 m track. In Japan, a 280 m track connected two terminals at Narita International Airport, from 1992 to 2013 [51, 53].

The APM systems with the Otis Hovair® technology that are currently in operation can be seen in Table 2 with their corresponding characteristics. The APM systems in Austria and Switzerland are underground, while the others are placed on elevated tracks [53–57].

All systems were manufactured by Otis, POMA and, most recently, the Leitner Ropeways group. POMA and Leitner group developed the MiniMetro® [58–60], that joins the two companies expertise on cable-hauled drive and APM systems, and inaugurated the last TACV system at the Cairo International Airport, in 2013, that is show in Fig. 7.

Fig. 8 illustrates the Poma–Otis Hovair® ExpressTram at Detroit Metropolitan Airport.

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Table 2. Technical data of low speed TACV prototypes

APM System	Site / Opening Year	Application	Supplier Company	Passengers/ cabin capacity	Speed (km/h)	Track length (m)
Dorfbahn Serfaus	Serfaus, Austria 1985	Sky Resort 4 stations	TTI Otis Hovair®	135	40	1300
Sun City Monorail	Sun City, South Africa 1986	Casino Resort 2 stations	TTI Otis Hovair®	N/A	40	1700
Cincinnati Airport People Mover	Cincinnati, USA 1994	Airport link 3 stations	Poma–Otis Hovair®	210	40	472
Getty Center Tram	Los Angeles, USA 1998	Museum 2 stations	Poma–Otis Hovair®	100	15	1200
HubTram	Minneapolis, USA 2001	Airport link 2 stations	Poma–Otis Hovair®	47	42	340
ExpressTram	Detroit, USA 2002	Airport link 3 stations	Poma–Otis Hovair®	114	48	1100
Huntsville Hospital Tram System	Huntsville, USA 2002	Hospital link 4 stations	Poma–Otis Hovair®	42	24	580
Skymetro	Zurich, Switzerland 2003	Airport link 2 stations	Poma–Leitner MiniMetro®	112	50	1100
MiniMetro Cairo	Cairo, Egypt 2013	Airport link 4 stations	Poma–Leitner MiniMetro®	170	50	1800

Note: N/A = data not available.

Fig. 7. Cairo International Airport MiniMetro®
(Courtesy from Leitner Group)

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Fig. 8. ExpressTram at Detroit Metropolitan Wayne County Airport
(Source: Wikimedia, CC BY-SA 3.0)

TACV EVALUATION AND COMPARISON OF TACV AND MAGLEV

Based on the historic development of TACV and its technical characteristics, this section will make an evaluation of TACV systems and propose a comparison of TACV and MAGLEV on their corresponding features.

The High Speed TACV historic analysis evidence that none of the projects flourish and failed the attempt to provide a solution to the intercity and long distances transportation.

First, the scenario was very optimistic about the maturity stage of the air cushion technology for ground transportation, that considered a short term until it was ready for implementation and operationally feasible, like the hovercrafts. Many national railway operators, like in the United Kingdom and France, didn't share enthusiastic perspectives about unconventional technologies, like the TACV, and persisted with the development of wheel-rail HST, that presented higher readiness level [29]. Therefore, the first generation of wheel-rail HST spread out across Europe, particularly in France, Germany, Italy, Spain and Sweden, that followed the success of the Japanese *Tokaido Shinkansen* [8].

It should be noted also that all national high speed TACV projects were finished in the period between 1973 and 1977. One of the explanations for this lack of coincidence was economical. In 1973, an oil crisis that increased the commodity prices caused in the subsequent years, mainly in the western countries, economic problems that ended with almost 20 years of continued economic growth. The aftermath of this incident was the reduction of governmental investments in many sectors, including transportation, and a

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budget trade-off between the deficit control and incentives to new technologies to decrease the fossil fuels dependence.

The second reason was due to technical factors that became the high-speed MagLev trains more attractive than their corresponding TACV. The power consumption required for the suspension system was much higher on TACV than on an EML MagLev. According to [29], the Tracked Hovercraft estimated a power of 2200 kW to float a 40-ton vehicle, while it would be necessary only 40 kW on the Transrapid. The Table 1 shows a mean power density with an order of magnitude of 25 kW/ton for the suspension system, while an equivalent EML train requires 1 to 2 kW/ton [38, 61]. The fans and blowers of an air cushion system also contributed to increase the vehicle weight and reduce the useful space for passengers, corresponding to 15 % of the weight [29].

The noise at high speeds was also a TACV drawback. While the *Transrapid* 07 (TR-07) presented a noise level of 84 dBA [36], at 400 km/h, the Rohr UTACV reached 95 dBA [43], at 230 km/h.

These factors explain the shift to financial and research interest to MagLev trains in Germany [37], that decided for the EML system, in Italy [34] and the USA [62] that followed the EDL system with superconductors at cryogenic temperatures.

Another aspect that contributed to high speed TACV failure was its propulsion system. The initial proposed short stator double-sided LIM [63] was not appropriated for high speeds systems for safety reasons, because the aluminum reaction sheet that is placed in between the two sides of the stator could bend and beyond the thrust loss at the track joints [26]. The short stator single-sided LIM also had problems of power transmission to the vehicle at high speeds and increased the vehicle weight with power conversion equipment [64]. For instance, in the Tracked Hovercraft, the power electronics inverter weighed alone 13-ton whereas the overall weight of the RTV 31 was 23-ton [26].

The other propulsion methods used on TACV, like propellers, jet engines or rockets, were not appropriate for ground transportation for their high noise and high fuel consumption, besides their environmental problems. The most suitable propulsion system for high speed contactless trains was employed only in 1977 on *Transrapid* 05 (TR-05), that used the long stator single sided LSM, and decisively contributed to technical feasibility of the HST EML MagLev [65, 66].

Table 3 presents a comparison between the TACV and the main MagLev methods. TACV needs a fan and pneumatic systems to distribute the air pressure and can float any kind of material. The EML system requires an interaction between ferromagnetic materials, the EDL needs a relative movement between conductors and ferromagnetic materials, while SML demand the interaction of ferromagnetic materials and superconductors.

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The airgap order of magnitude in TACV, EML and SML MagLev systems are equivalent, while the biggest airgap is found on EDL MagLev. The pressure order of magnitude is figure of merit that indicates the amount of suspension force that is available over a surface. In this topic, the EML MagLev is better than all the others, while the TACV has the worst result [16, 67].

From the control systems perspective, it should be noted that the TACV is naturally stable and requires only a control loop to improve the vehicle suspension and the ride comfort, being insensitive to external disturbances. The EML, on the other hand, are naturally unstable and require a complex control loop and a redundancy system to keep the vehicle floating at the set-point position. The SML doesn't need any control system, while the EDL requires the null-flux arrangement for guidance and levitation stability, and additional active damping control [16, 68].

Table 3. TACV and MagLev comparison

Levitation System	Floating material	Airgap order of magnitude (mm)	Pressure order of magnitude (N/cm²)
TACV	Any	10	1
EML MagLev	Ferromagnetic	10	100
EDL MagLev	Conductor	100	10
SML MagLev	Superconductor	10	10

Considering the urban TACV, and most specifically the Hovair® technology, it's possible to note a consolidated market niche. The Hovair® system is being applied in touristic, hospital and airport links, as can be seen at Table 2. Its currently version, the MiniMetro® with air cushion suspension, keeps the cable-hauled propulsion. The main advantage is the vehicle weight reduction since it doesn't need on-board motors inside. However, the cable-hauled system produces friction losses and requires machine rooms at its installation site, and large maintenance costs.

According to [51] and [52], the Otis Hovair® significantly reduced the power consumption and noise of the ACV suspension system, when compared with the high-speed TACV. Its ACV suspension power density has an order of magnitude of 1 kW/ton, which is equivalent to EML MagLev. For instance, the first urban MagLev, at Birmingham Airport (UK), was designed for 2 kW/ton [69].

The comparison of Hovair® and urban MagLev shows some similarities between them. Both trains run on segregated tracks, like undergrounds or, more commonly, elevated tracks and don't interfere on local traffic. The levitation systems distribute the load on the support structure, which reduces the civil engineering costs and provides lighter and compact infrastructure [70, 71]. The vehicle operating speeds of 50 km/h to 60 km/h, and maximum gradients close to 10 % of both suspension systems are equivalent and even superior to light rail vehicles (LRV) [72].

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The main Hovair® and MiniMetro® limitation is the track distance, that doesn't must be superior to 5 km to maintain its economic feasibility [73], while MagLevs don't have track length restriction. The radius curves are also a restriction factor for the ACV vehicles, while, for instance, the EML MagLev HSST [74], in Japan, or the SML MagLev-Cobra [70], in Brazil, can accept minimum curves of 50 meters.

CONCLUSION

This paper presented the TACV history development for high speed and urban transportation. It could be noted the research done at six different countries – Brazil, France, Germany, Italy, United Kingdom and USA – to develop a reliable and feasible high-speed train using the ACV principle. However, all projects failed for many reasons, from the insensitivity or anticipated mistrust of public planners and traditional rail operators to technical inadequacy of some characteristics that caused their shift to MagLev trains or the maintenance of wheel-rail perspective over the long run.

In this sense, the 50 years of high-speed MagLev research in Germany and Japan, shows the technical feasibility and the great potential of magnetic levitation technique, despite its drawback of intermodal compatibility, and provides good lessons about the synergy between industry partners, rail operators and government to achieve a more reliable and efficient transportation system.

The urban TACV – the Hovair®/Minimetro® – have found a well stablished market niche at straight and short distance tracks, like resorts, museums, hospitals and airports, and currently provide a competitive APM commercial solution when compared with other conventional modes of transportation. Although this expertise to mean an entrance barrier to new MagLev competitors, the absence of limitation factors, as track length or radius curves, ally with a non-contact, non-wear and lower noise LIM propulsion are good advantages that make the MagLev more attractive than the TACV for urban transportation.

It's important also that MagLev manufactures provide full APM solutions for customers' needs, as the Minimetro®. Currently a good effort is being doing on this subject by *Transrapid* for its high-speed product [75].

Finally, it is expected that the Maglev planners know the TACV history – its failure for high-speed and success for urban transportation – and learn important insights for the Maglev development, that besides its competitive advantages may convince the decision makers of its suitability at different markets.

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