“SKYTRAK” LOW CARBON VERTICAL TRANSPORTATION SYSTEMS FOR THE 21ST CENTURY

Adrian GODWIN ***BSc DMS MCIM CEng MIET***

Chairman

Lerch Bates Ltd., UK

ABSTRACT

There has been much talk over the past thirty years or more about the dream of having more than two passenger cabins travelling in one lift shaft. Why? Because of the innate efficiency gains, especially for very tall buildings, that would follow such a quantum leap in passenger handling capacity for any given lift shaft.

Of course, to even attempt this would require one to dispense with suspension ropes as well as the “beautiful” counterweight potentially losing a device that, for over 100 years, has provided a degree of efficiency in conventional electric traction lifts as we know them today.

The attraction of “Skytrak”, a radically new form of vertical transportation, is that it dispenses with suspension ropes and counterweights and, in the process, offers architects a completely new degree of freedom for transporting people around and between buildings thereby unleashing the potential for new building designs and visions for new live, work, play “green” communities of tomorrow.

This new space and energy efficient approach to moving people uses linear motors and “retarders” to give vertical transportation its new found independence yet inherent safety. In this paper the work done in identifying many of the new low carbon opportunities for Skytrak to move people both horizontally and vertically is explored and explained.

1. BACKGROUND

In the world of commercial property development at the dawn of the 21st century the following drivers are all too apparent:

- Density of occupancy of all buildings is increasing
- Land becomes ever scarcer and more valuable
- Buildings have to get more efficient
- Elevator systems have to work harder!

In addition we see that architects desire the following;

- A new degree of freedom for vertical transportation systems i.e. passenger cabins that move outside the vertical plane
- New energy efficient “green” self-contained communities need to be established where people can live, work and play
- Multiple cabins need to travel in one shaft to reduce the number of lift shafts deployed in buildings to save space
- Passenger cabins need to move people within and between buildings and facilities to remove day to day use of cars

Further, requirements are changing because;

- Building geometry is becoming more complex
- Steel, glass and other materials can be custom cut
- Architects want unique shapes of buildings
- Transit between buildings and complexes is required
- Need to move people from major transportation hubs
- Building in city centres very constrained
- New integrated transportation solutions required

Examples of proposed buildings incompatible with conventional vertical transportation systems:

Figure 1

July 2010 Beijing CBD
Competition Entry

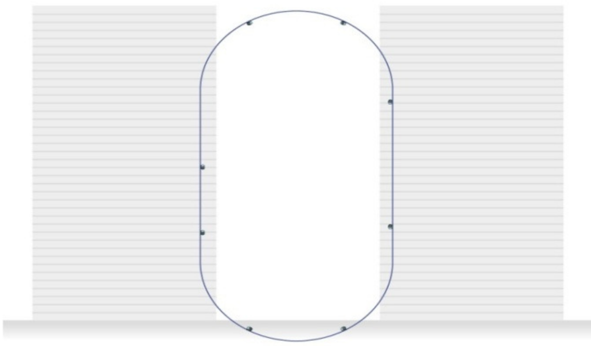


Figure 2

Proposed “Loop” Vertical
Transportation System
serves twin towers

Other proposals include the concept of a multi-use development where the building user is only one lift journey away from any day to day activity. Such a circular vertical transportation enables a true live, work and play community to be developed whereby the building occupant has no day to day need to leave the building saving on using external forms of transportation.

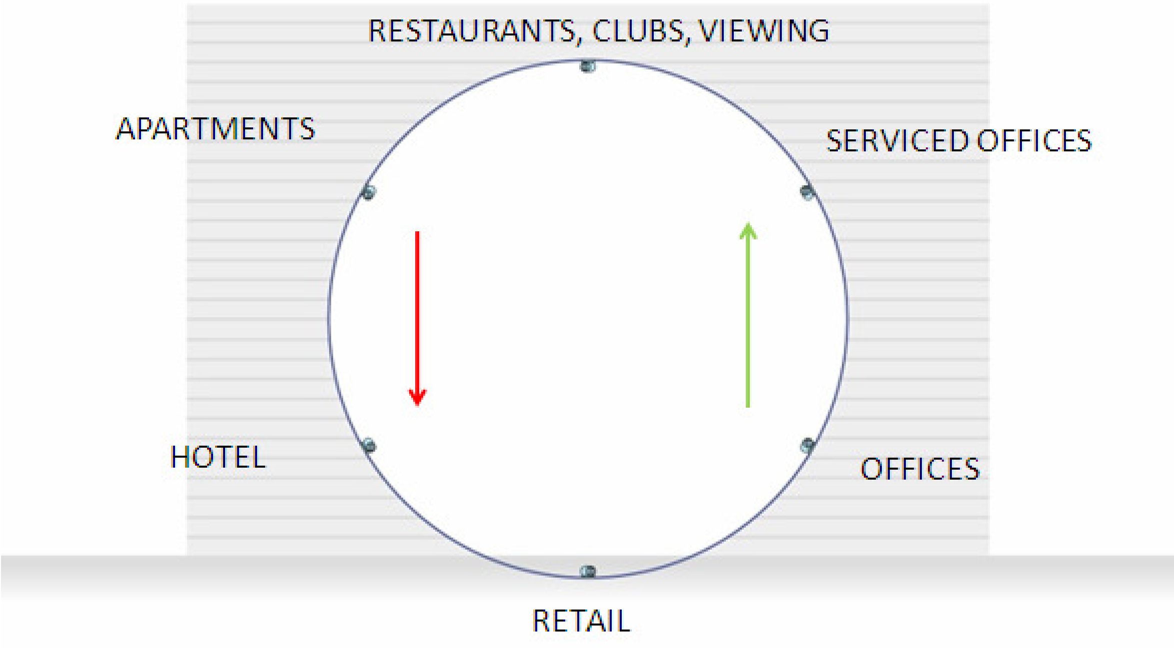
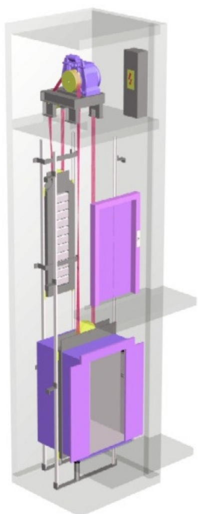


Figure 3 Concept building for a new "green" community development

2. CONVENTIONAL ELECTRIC TRACTION LIFTS

It is only when one considers dispensing with the balance weight that one realises how heavily reliant upon this simple device the basic design of most traction lifts are. Some of the many advantages of the "beautiful" counterweight include:



a) Minimising the energy input required to hoist a given load.
b) Minimising deceleration forces especially when "emergency" stops are made.
c) Displacing the local structural loads of the cabin, usually to high level.
d) Simplifying emergency release operations.
e) The large masses significantly contribute to the smoothing of the passenger ride quality.

To reinforce the many advantages of using a counterweight let us imagine for a moment some of the implications of a decision to remove the ropes and the "beautiful" counterweight. These include:

Figure 4 shows typical electric traction lift with counterweight

1. Probable increase in local shaft structural loads of approximately 4-5 times
2. Probable increase in drive motor power by approximately 4-5 times
3. Potential increase in energy losses of approximately 4-5 times
4. Transmission of power and data to/from the lift car without trailing cables
5. Increase in the braking force required from the fail-safe brake
6. Manual release of the fail-safe brake for passenger release not practical
7. Serious problem of dealing with emergency stopping in either direction
8. Control of headway between cabins and capability to take cabins off the track

In addition the basic safety of such lifts, in case of loss of suspension ropes, has been assured since the invention of the safety gear by Elisha Graves Otis in 1853. Dispensing with suspension ropes and the counterweight will, most likely, entail the elimination of this safety device as well.

3. PURSUIT OF INCREASING BUILDING EFFICIENCY

It is the goal of building designers and especially vertical transportation consultants to continually improve building efficiency i.e. the net to gross built floor areas such as to increase the proportion of that more valuable part of the building which is the "rentable" or "saleable" element.

In recent years' consultants and designers' attention has been focussed upon such techniques as:

- Use of double deck lifts and 3-D "Double Deck Destination" Control
- Use of Shuttle & Local Goods Lift Services similar to Passenger Lifts
- Time Sharing of Lifts to achieve 24 hour utilisation (multi-use towers)
- "Twin Lift" solutions for passenger and goods lift service
- Combining Different Uses of Decks/ Entrances at Different Times

All of these are being pursued for one simple expedient i.e. minimisation of the space taken out of the building by the lifts. The next logical step for vertical transportation efficiency is to have multiple cars travelling in the same shaft simultaneously. This would represent the modern day equivalent of the old-fashioned "paternoster" lifts or "cyclic elevators" first installed in 1884.

4. BASIC LAWS OF PHYSICS AND ELECTRODYNAMICS

As will be seen a law of electrodynamics established 20 years before the invention of the safety gear in 1853 holds out the prospect of providing a new form of intrinsic safety for passenger cabins travelling without suspension ropes and a balance weight in the 21st century.

Lenz showed how electromagnetic circuits must always obey Newton's third law. Lenz's law says:

"An induced current is always in such a direction as to oppose the motion or change causing it"

With the advent of relatively low cost high power rare earth magnets one can arrange such material to be fixed along a track upon which a passenger cabin travels. The cabin can also be arranged to have attached to it a series of stator windings that pass through the magnetic field. If those windings are made to form a resonant circuit by the introduction of a capacitor the resultant tuned generator circuit can be designed such as to produce a force opposing the direction of movement (down under gravity) of the cabin such as to limit the speed of descent based upon the resonant frequency which is governed by the size of the capacitor. The stator windings behave like a "retarder" limiting the descent velocity. The lost energy is dissipated as mechanical friction and heat in the resistance of the generator inductance.

Thus it is that, independent of the availability of power supplies, switches etc., that a passenger cabin could be made intrinsically safe from free fall using the "retarder" properties of the windings carried on the cabin thereby negating the need to carry the "old fashioned" safety gear.

When it comes to the power requirements to move a ropeless lift as against a conventional electric traction lift the following diagram illustrates the basic equations that apply demonstrating the much higher power requirements necessary for such passenger cabins.

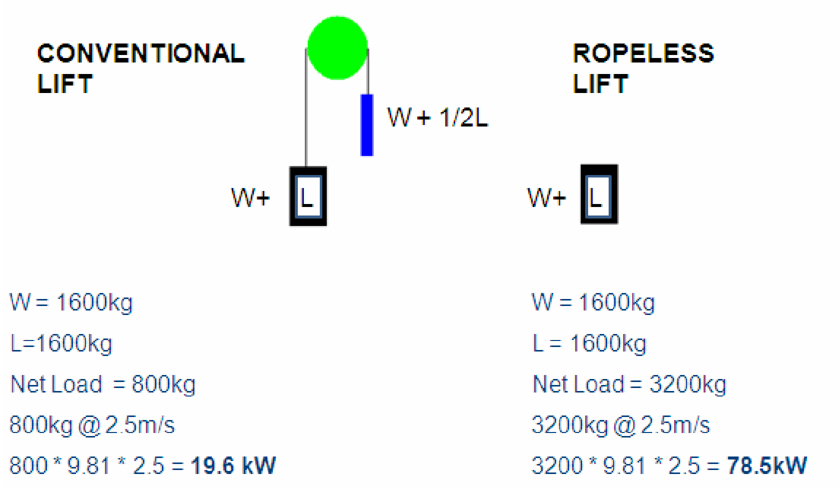


Figure 5 Comparison of Power Requirements for Roped versus Ropeless Lifts

5. COUNTERMEASURES TO POWER INPUT TO ACHIEVE LOW CARBON ALTERNATIVE

In order to combat the potentially much larger losses arising from driving a ropeless passenger cabin without counterweight the following are some of the countermeasures proposed to be adopted:

a) Arrange for a common d.c. power bus to feed both “Up” and “Down” travelling lift cabins. Energy from “Down” cars is fed back into the bus to feed “Up” travelling cabins.
b) Maximum use of light weight components, composites and alloys. The analogy is the aircraft industry and the need to reduce all up weight of the cabin.
c) Run the system at the lowest speed consistent with acceptable time to destination requirements.
d) Ensure losses are minimised, overall efficiency 96% plus.

6. SKYTRAK DESIGN CONSIDERATIONS

Some basic considerations concerning the practical design of a multicar ropeless lift system.

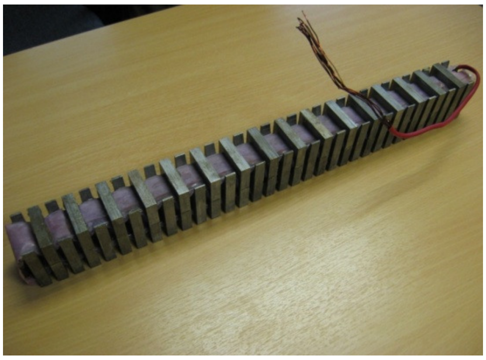
- Simple, efficient and quick mechanism for moving lift cabins from UP to DN and DN to UP at terminals if they do not follow a continuous loop
- Secure wireless communication to transfer commands from main control to moving lift cabins
- Satisfactory means of dealing with trapped passengers in an emergency
- Failsafe brakes must now be carried on board
- Increased structural loads will be applied to support track
- Keep cars “on” a track at all times
- Light weight materials to be used throughout
- Cabins to be kept vertical when on curved trajectory
- Ride quality like today’s best passenger lifts
- Lightest drive motor with the right characteristics
- Satisfactory control of deceleration in the UP direction when emergency stopping occurs
- S peed consistent with meeting ATTD (average time to destination) criteria
- Safety is paramount - all EHSR’s (Essential Health and Safety Requirements) must be met
- Minimise overall system cost

7. DOUBLE SIDED, “CLAW” TYPE, HIGH OUTPUT LINEAR MOTOR

One of the keys to commercial realisation is a form of linear motor that has a high “power to weight ratio” and is simple and relatively inexpensive to mass produce as this is the device that provides the means to propel passenger cabins both vertically and horizontally. The form of linear motor proposed has been built in sufficient quantity to enable its performance to be analysed in depth.

- Simple construction lends itself to automated production

- Double sided to maximise output
- Single winding embraces large number of poles and can be shaped for circular applications
- Moving magnet weight 30kg per metre
- Stacked in sets and operated as three phase
- Force output 5000 N per metre for three phases



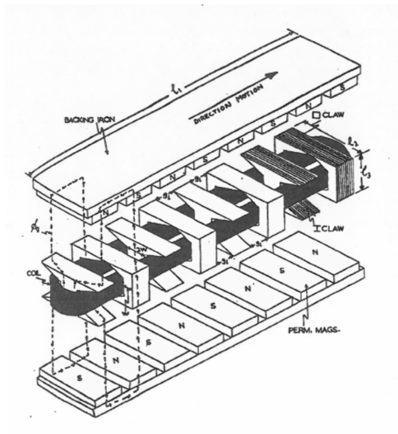


Figure 6 Illustration of the form of the linear motor (cross section approximately 50mm

8. THE TRIPLE FUNCTION "RETARDER"

The "retarder" discussed earlier which is simply a section of stator windings held "on board" the moving passenger cabin is used in three different ways depending on the circumstances.

1. It acts as a generator when moving to ensure the "on board" battery pack is continuously recharged.
2. It acts as a motor with sufficient force output such that when emergency up stopping occurs it will provide satisfactory deceleration of the lift cabin in conjunction with its power invertors and super capacitor pack.
3. It acts as a "retarder" capable of supporting the gross weight of the lift cabin and controlling its descent at a slow speed < 1.0 m/s enabling the lift cabin to return safely to floor level and discharge its passengers.

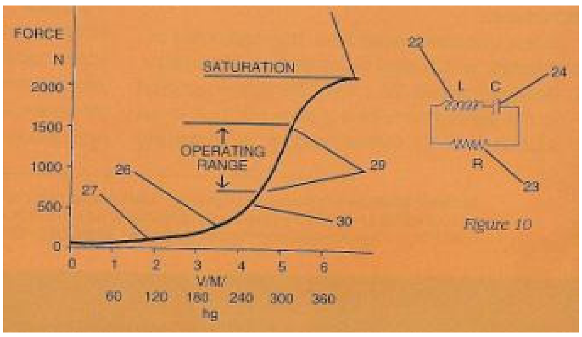


Figure 7 The retarder under 6m drop test and the tuned resonant circuit controlling speed L

9. TRANSPORTATION SOLUTIONS

The invention of the tuned "retarder" has spawned a complete new family of vertical transportation solutions that involve three types of "prime mover" which can be summarised as follows:

a) Controlled descent using the tuned "retarder" as a simple "gravity" drive

b) Low speed (up to 2.5 m/s) rotational linear motor drive

c) High speed (up to 6.0 m/s) linear motor drive

In addition five important inventions, together, open up the possibility for a new degree of freedom for "Skytrak" and vertical transportation systems of the future. These are:

a) Use of the tuned "retarder" to allow safe descent under gravity under all conditions

b) Passenger transportation on an aerial ropeway

c) Emergency "up stopping" solution for high speed

d) Gearless lantern pinion drive using rotational linear motor for low cost / low speed drive

e) Simple "terminal switching" device to move cars from "up" to "down" shafts

The above inventions having been completed, within this paper are described five "Skytrak" applications which can be summarised as follows:

- EGRESS Personal Rapid Escape Device
- SKYTRAK Multi-Car Aerial Ropeway System
- SYNCHRORAIL Multi-Car Horizontal Transportation System
- SKYTRAK Multi-Car Circular Vertical and Horizontal Transportation System
- SKYTRAK Multi-Car Vertical Transportation System

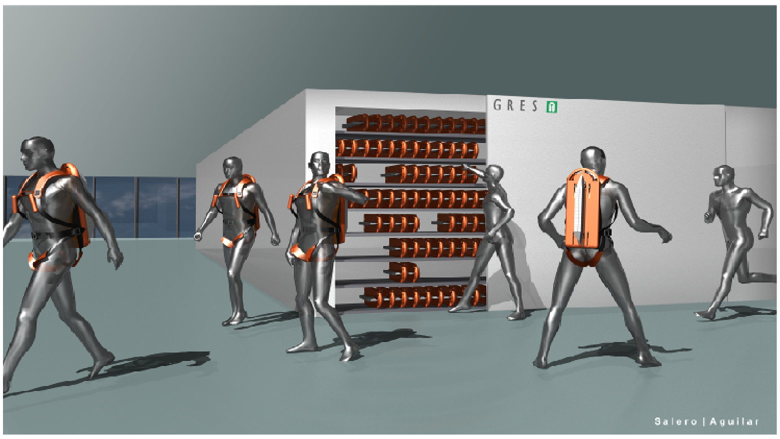


Figure 8 Use of EGRESS by building occupants taking their "lifejackets"

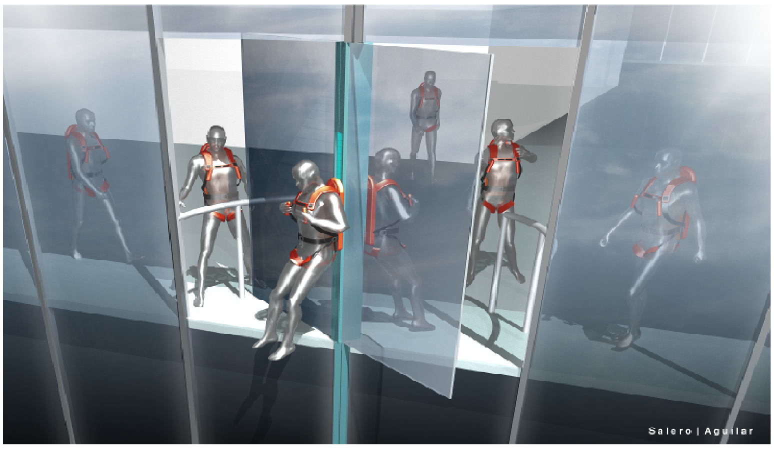


Figure 9 Mullions in building cladding system contain magnet tracks

Figure 10 Occupants descend at constant speed to aircraft chute at base

Figure 11 “Skytrak” Multi-Car Aerial Ropeway System with “Gravity” Drive

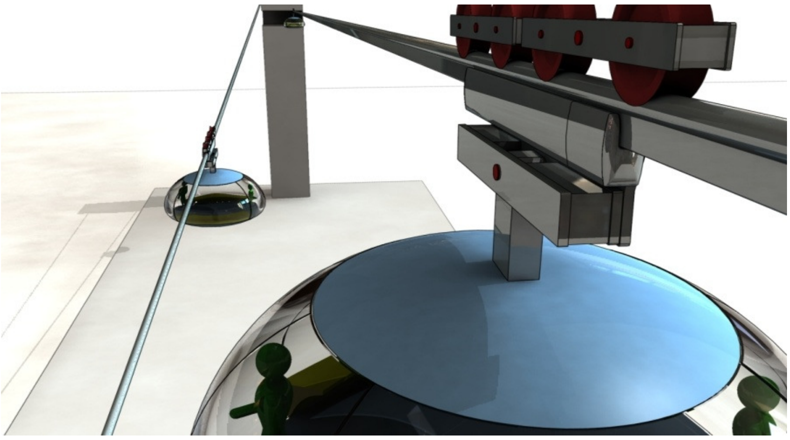


Figure 12 “Skytrak” Multi-Car Aerial Ropeway System with “Retarder” in Magnet Track on Ropel

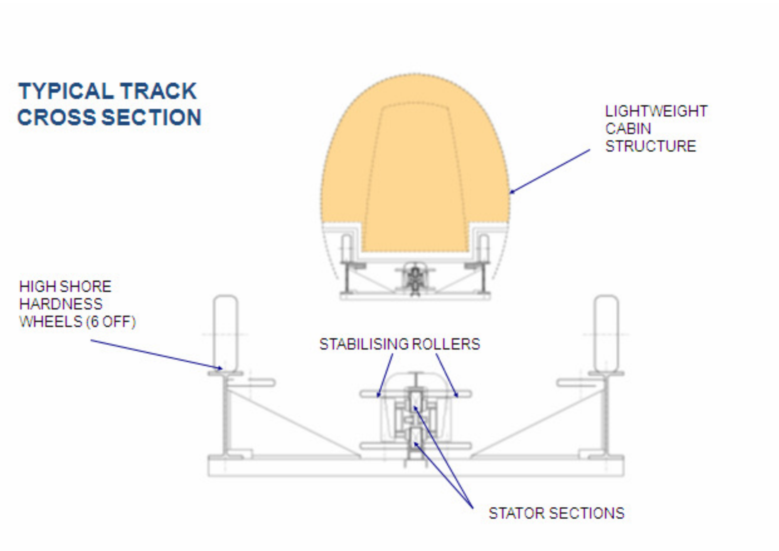


Figure 13 Synchrorail Cross section of track and passenger cabin

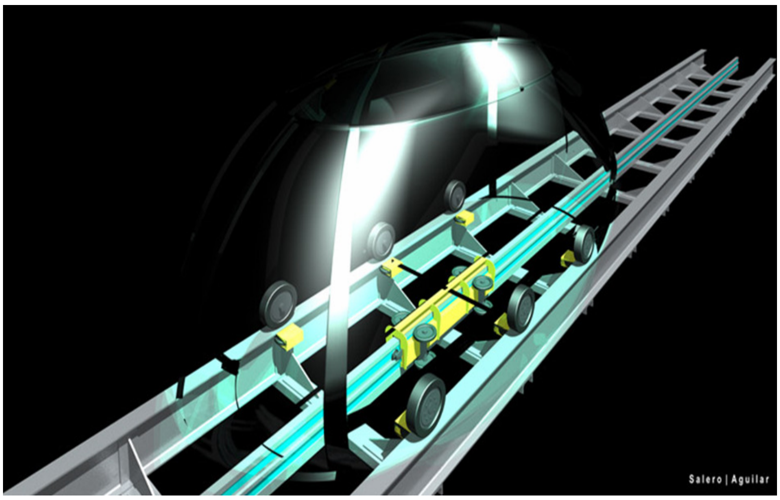


Figure 14 Synchrorail uses lightweight cabins and has virtually no moving parts

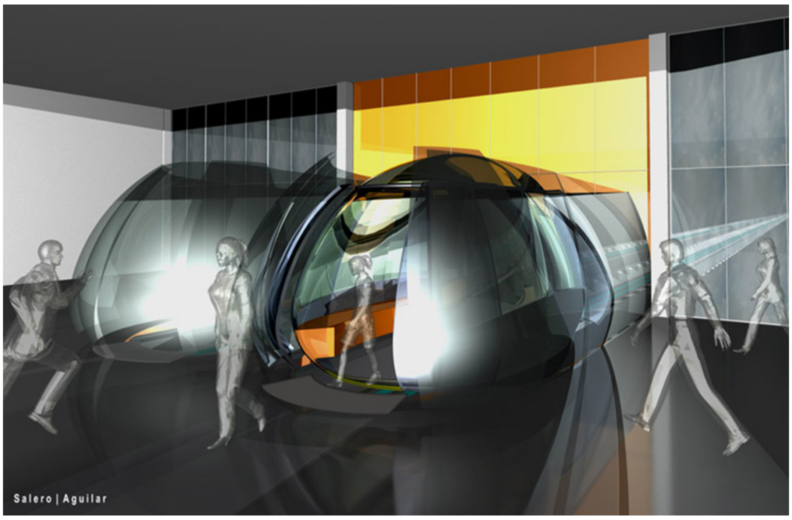


Figure 15 Synchrorail has a ride quality and journey experience similar to a shuttle elevator

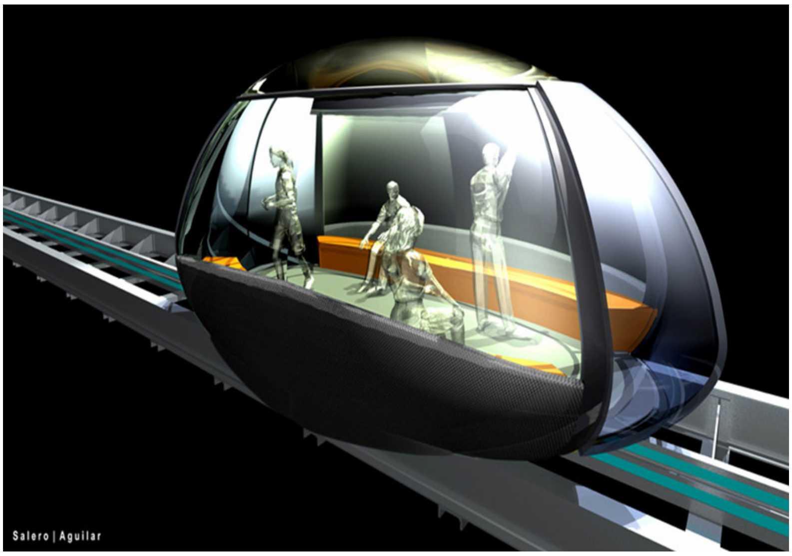


Figure 16 Synchrorail can be used in all weather conditions and allows for handicapped access

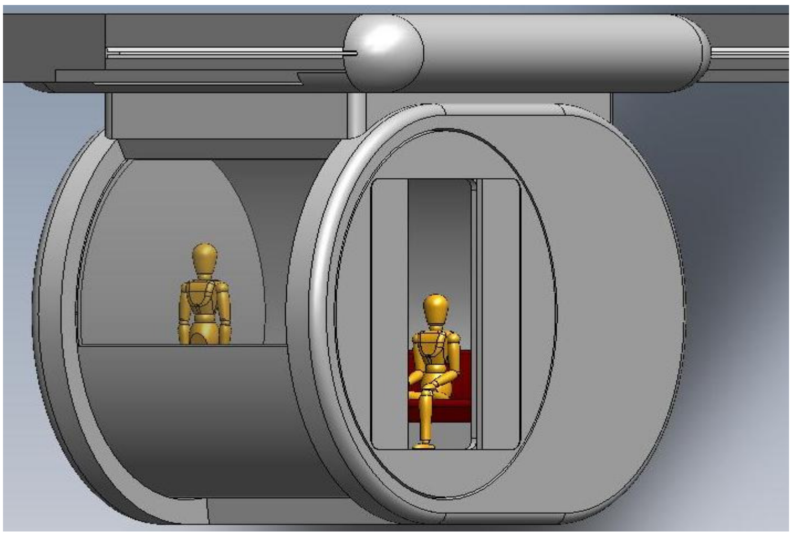


Figure 17 "Skytrak" Circular Transportation System has a Rotating Cabin

Car, Doors, Floor, Seating etc 150kg	Cabin External Enclosure 50kg
Motor 523kg	Retarder 132kg
Slewing Ring 30kg	Slip Ring 10kg
Brakes 140kg	Logic Controller 10kg
Guide Wheels 100kg	Door Operator 20kg
Wireless Communication 5kg	Battery 60kg
Inertia Switch 1kg	Lift Position Information 1kg
Capacitor Pack & "Tuning" 85kg	Normally Closed Contactors 15kg
Load Switch 5kg	Up Stopping Drive 10kg

Figure 18 "Skytrak" Breakdown of Cabin Weight 1597kg

Figure 19 "Skytrak" Multi-Car Circular Transportation System operating on 360 degree tracks

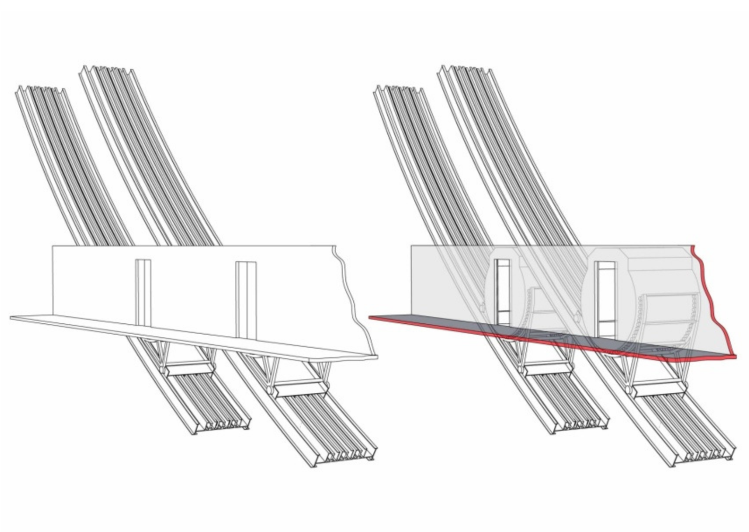


Figure 20 "Skytrak" Multi-Car Circular Transportation System uses conventional fire rated lift doors

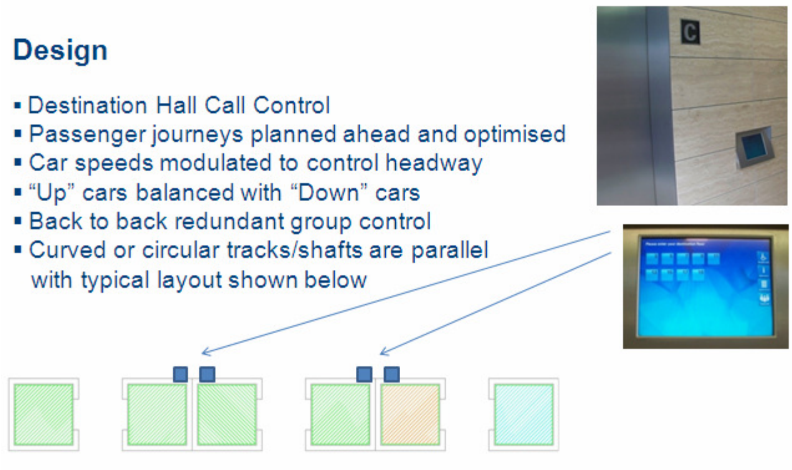


Figure 21 "Skytrak" Multi-Car Circular Transportation System Traffic Control and Lobby Design

10.0 HIGH SPEED STOPPING IN THE "UP" DIRECTION

At high speed an emergency stop in the "up" direction or combination of "up" and "horizontal" trajectory could cause considerable passenger distress and potential injuries. A recent invention described here may represent the solution to that last item.

The following diagrams illustrate the concept of how one or more cabins might travel on a track and how some of the safety solutions would operate.

Figure 22 The main track structure is shown comprising three double sided linear motor stator sections (black), twin magnet tracks for not only safety retarding under gravity and on-board power generation but importantly deceleration control during emergency "up" stopping. Track side power switching devices are also shown

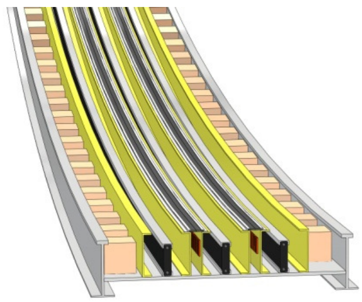
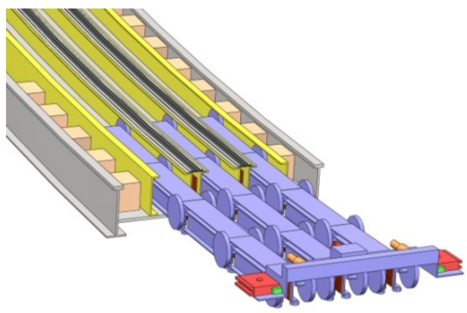


Figure 23 The main drive moving magnet assembly (blue) is shown here complete with articulated sections, guide wheels and brakes (red)



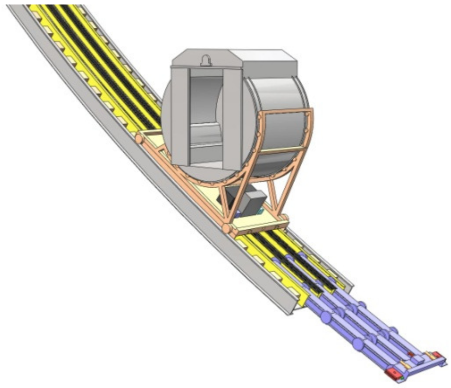


Figure 24 The passenger carrying assembly is shown here as a lightweight structure of approximately 3m diameter in the form of a drum (grey) which can rotate to remain vertical at all times. The whole cabin has a low centre of gravity. The retarders, attached to the cabin, engage the twin magnet tracks under the main cabin assembly so as to avoid passenger entrapment by allowing the cabin to return to the nearest floor under gravity at low speed. Wireless data transmission, batteries and a super capacitor pack are also mounted on board.

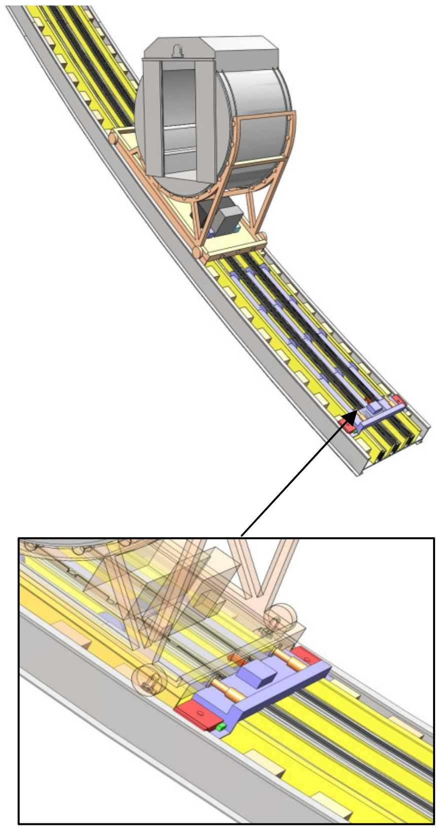


Figure 25 The passenger cabin is stopped at high speed e.g. 6.0 m/s in the "up" direction. The main drive assembly stops more or less instantly using its failsafe brakes whilst an inertia latch permits the cabin assembly to become detached from the main drive assembly and continue to travel forward under its own momentum. To assist this momentum and provide a comfortable slowdown, taking perhaps 3s or so, instant power from the on board super capacitor pack is connected to the retarders which then become motors.

After this controlled deceleration the cabin then rolls back, with the retarders reconnected with their tuning capacitors, at controlled speed to rejoin the main drive assembly and thence to continue its safe descent downwards at low speed to the nearest floor served or the lowest part of the track system for release of passengers

11.0 REDUCTION IN CORE SPACE TAKE USING "SKYTRAK"

A number of case studies have been conducted to ascertain the relative efficiency of a "Skytrak" vertical transportation system over conventional single and double deck lift solutions. These studies have tended to indicate that in any substantial scale of commercial building would benefit greatly from the efficiencies that can be obtained by deployment of such a system and the value of the space released.

Typically the value of the space released represents many times more than the cost of deploying the "Skytrak" solution and the reduced number of lift shafts and construction materials required means the vertical transportation solution is potentially much "greener" and more sustainable.

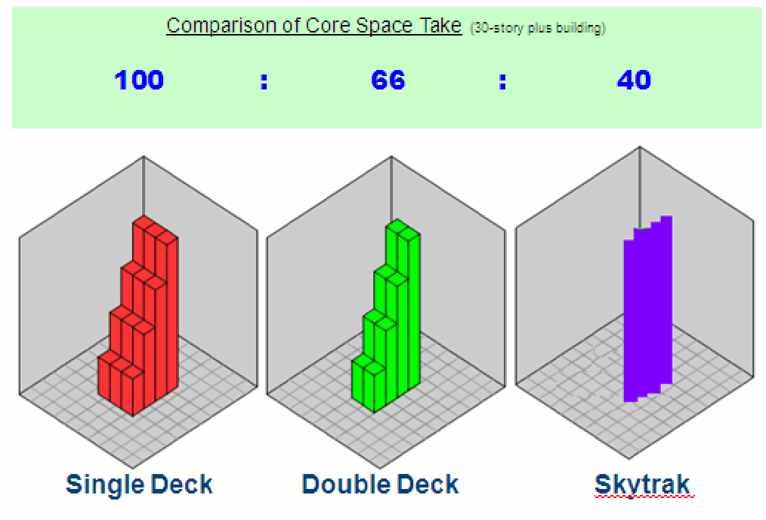


Figure 26 Illustration showing Relative Efficiency of Vertical Transportation Solutions

12.0 "SKYTRAK" MULTI-CAR VERTICAL TRANSPORTATION SYSTEM

A recent invention enables the possibility of using the linear motor drive with the safety "retarder" in the form of a low cost circular linear motor with a lantern pinion arranged in the form of a rack and pinion drive. This might be suitable for speeds up to 2.5m/s.

Shown below are the key elements of this novel form of gearless drive that would be mounted on the passenger cabin. Its low speed, gearless design and use of a lantern pinion constructed from new composite materials would make for a low noise drive mounted "on board" the passenger car.

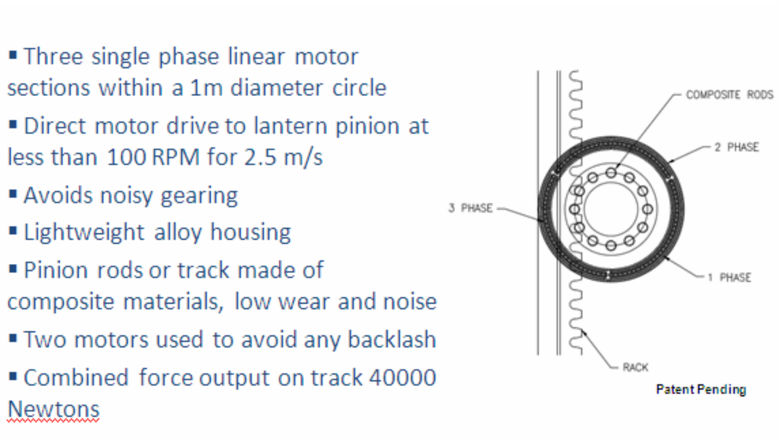


Figure 27 Circular Linear Motor and Low Speed Lantern Pinion Drive < 2.5 m/sec.

When this type of drive is applied to a conventional "through car" built in lightweight composite materials there is an opportunity to deploy a multi-car solution in one lift shaft. The cars are cantilevered from a central spine track which is located centrally between two adjacent lift shafts. The spine only contains the rack, the d.c. power bus and a set of guides.

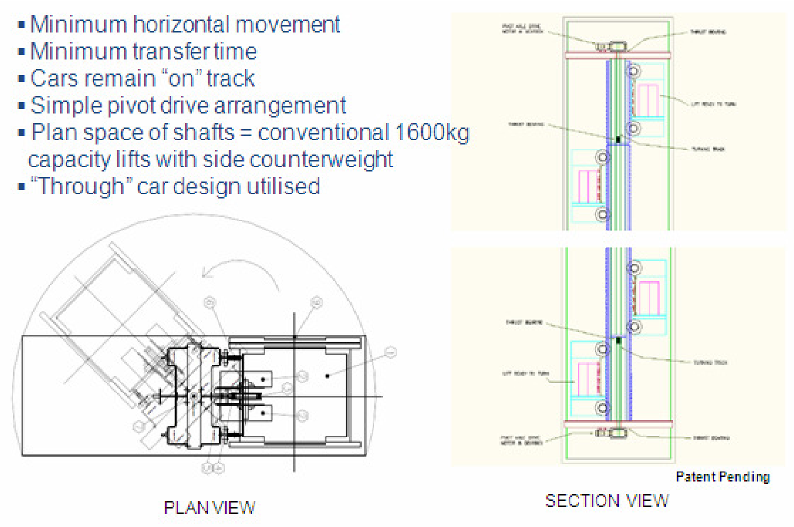


Figure 28 Terminal "Switches" located at Top and Bottom of each of the Adjacent Vertical Shafts

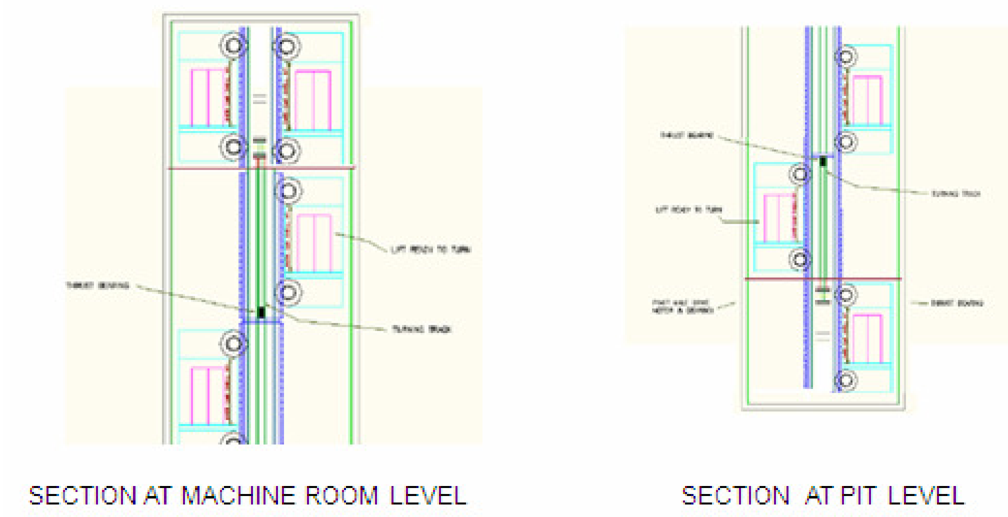


Figure 29 Terminal Parking and/or Servicing areas are placed above and below the "Switches"

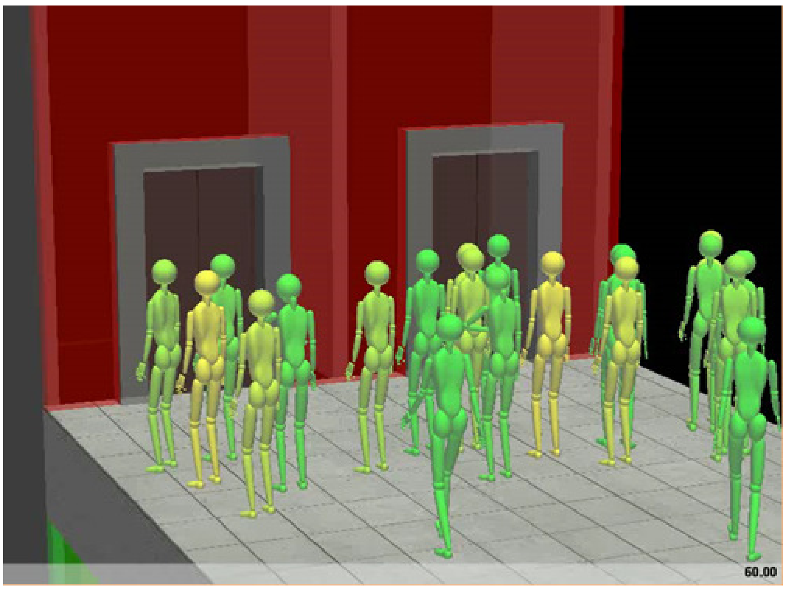


Figure 30 Simulations of "Skytrak" Vertical Transportation Systems show many Advantages

13.0 CONCLUSIONS

The invention of the tuned "retarder" has opened up the prospect of a new wave of vertical transportation solutions for the 21st century.

These systems have the opportunity to be more energy efficient and more space efficient.

In many cases they represent considerably quieter, lower cost alternatives to other forms of transportation used in city centres such as buses, trams and trains.

This new family of vertical transportation solutions will offer architects the new "degree of freedom" they want to make new building shapes and configurations viable. These solutions offer all the advantages of multiple cabins travelling in one shaft without the increased mechanical complexity of transferring cabins horizontally or on and off tracks etc. Being simple and building on at least some aspects of current lift engineering it is likely to provide a more reliable service. Most importantly the ride quality should be substantially as a traditional elevator.

As a result of recent feasibility studies and accompanying inventions there is now a body of work available to realise these important developments in vertical transportation in practical terms.

It is hoped that at some point during 2011 prototypes of some of the solutions presented here will be constructed to ensure passenger ride quality can be achieved and for the necessary safety type testing and certification to be obtained. Therefore let us ask architects and building designers to dream about a new generation of 21st century low carbon buildings and communities wherein these new possibilities for vertical transportation will dominate their inherent design and use.......