ELEVATORING FRANK LLOYD WRIGHT'S MILE-HIGH BUILDING

James W. Fortune, President
Lerch, Bates & Associates Inc.-Elevator Consulting Group
Littleton, Colorado 80122-2709 USA
303 795-7956, FAX 303 795-0938

Abstract

Since its inception in 1956, the 528-story, 5280 foot high (1600 m) "Illinois" Office Tower, that was to be constructed on the lake front in Chicago, Illinois, USA, has inspired much debate, controversy and delight among Elevator Consultants as to the best method for providing elevator service in the project. As originally envisioned, the building was to be served by 76 quintuple (5) deck, atomic-powered, rack and pinion, 5000 FPM elevators.

This paper will explore the feasibility of elevatoring such a building, based upon the original designs and today's technology. We will then look at some practical lift schemes for handling the 18,462,000 sq. ft. (1,715,000 sq. m.), 130,000 (1956 estimate) occupant population. The paper will explore the application of conventional sky lobbies, top-down sky lobbies, car-car counterbalance and double-deck express lifts. The physiological problems associated with lift speeds in excess of 2000 FPM and rises in excess of 1000'and the impact of rapid atmospheric changes will also be explored. Finally, we will review some of the future changes that need to be developed in lift designs, car loading schemes, and propulsion methods in order to make a 150-story plus building a reality.

The Illinois Building

As envisioned by its Designer, Frank Lloyd Wright, the mile-high, 528-story Illinois Office Tower was to be a tripod-supported, 4-sided tapered structure that extended from the trapezium base floor, containing about 85,000 sq. ft., to the 528th level with only 288 sq. ft. of office space. The fabricated-steel building core was to be encased in light-weight concrete and goes from the taproot foundation that is anchored in bedrock and continues up through the building top. The tower structure looks like a rapier with its handle set firmly into the ground and its "blade" upright. The 528 tapered, hollow-weight concrete, post-tensioned, floor slabs are to contain the air-conditioning ducts, the lighting/suspended ceilings, and ancillary wiring, pipes, chases, etc. The floors radiate out from the central building core, much like branches from a tree trunk and are supported on their outer ends by steel, pendant-supported rods (cables). Much like a tripod, the building design is in perfect equilibrium so that wind or seismic pressures on any side are resisted by the other 2 sides. It is claimed that since all of the building support structures would be in perfect balance, this building, unlike conventional high-rise structures, would have no sway or displacement during a high-wind condition to adversely affect the elevator equipment.

In 1956, access to the building was to be via 4 major highways converging at the 4 building entry/exit points.

The base building structure (see Sketch 1) contains 5 parking levels (1 below grade) that can accommodate up to 15,000 automobiles. Portions of the garage roof are to contain 2 helicopter landing pads that can handle up to 50 helicopters each. The helicopter landing decks and the 5 parking levels are to be interconnected by a series of escalators for ease in transitioning between the multiple elevator deck loading/unloading floors. Since the building was planned to be served by quintuple (5) deck elevators with all decks loading and unloading simultaneously at the base entry/exit levels, the tenants and visitors would have to utilize the escalators for transport to the appropriate deck. The building is to be divided into 5 upper zones of roughly 100 stories each. The following chart indicates that the 5 upper-zone floors served and shows the amount of area included in each zone:

The Illinois Office Tower
Net Rentable Area Distributions

Elevator Service Zones	Floors Served	Estimated Net Rentable Area (Sq. Ft.)	Estimated 1992 Population (Persons)
Low Rise	LL1-LL5, 1-110	5,250,000	32,813
Mid Low Rise	LL1-LL5, 111-220	4,088,000	24,047
Mid Rise	LL1-LL5, 221-328	1,752,000	9,733
Mid High Rise	LL1-LL5, 329-428	850,000	4,474
High Rise	LL1-LL5, 429-528	369,000	1,845
Total	LL1 through 528	12,309,000	72,912

LL1-LL5 = Loading Lobbies 1-5

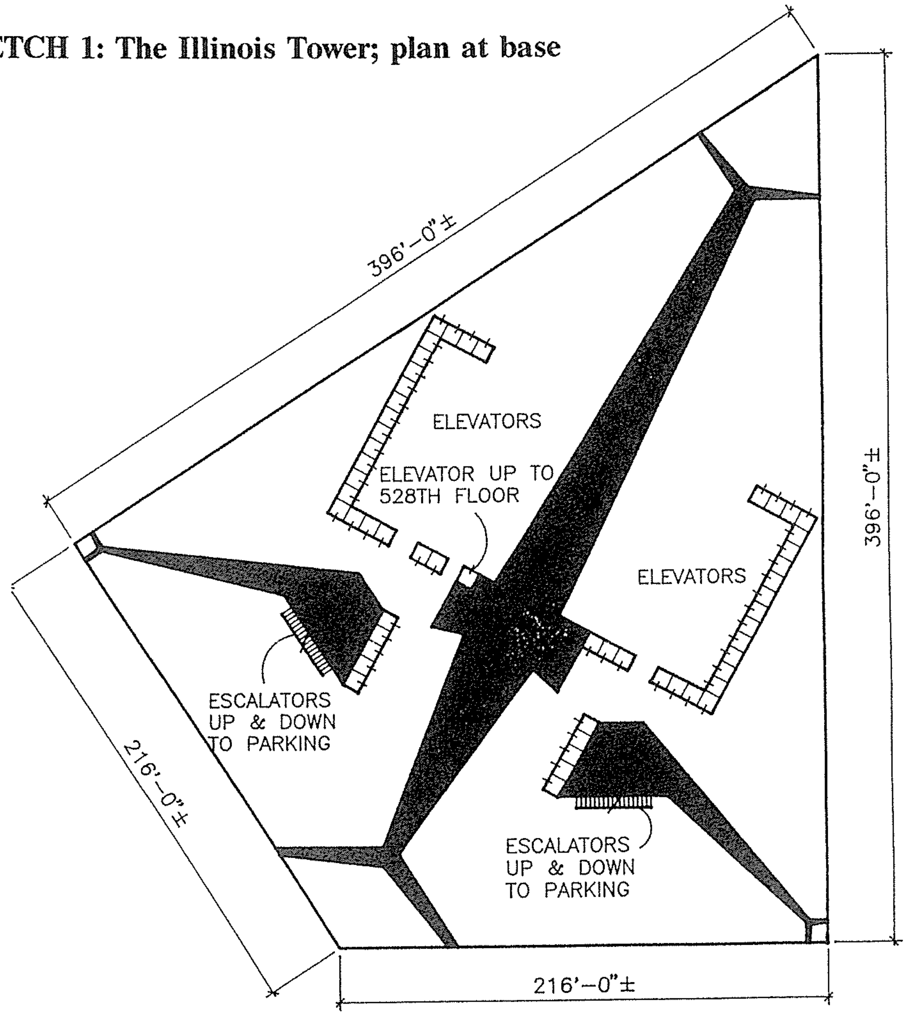
Since much of the detailed design information that is available for the Illinois Office Tower is sketchy, we must make some assumptions, based upon our perception of how the building would likely operate if it were built today, in order to proceed with our analysis. For instance, the original designs indicate that the floor heights would be 18'-0" for the first 20 stories and then 10'-0" thereafter. Since the elevatoring was to all be via multi-lift decks, the floor-to-floor distance and lift deck heights must be equal at all landings. Therefore, we have assumed all floor heights to be 10'-0" high.

There are no provisions for service or freight elevators; with 12,300,000 sq. ft. of rentable area, we would anticipate that at least 12-15 service elevators would be required.

The original plans show no provisions for mid-mechanical floors. A 500-story tower would obviously require multiple mid-mechanical levels which would either increase the building height or reduce the number of occupied floors. However, in this concept study, we have followed the Frank Lloyd Wright original designs and have not made allowances for any mid-mechanical levels.

The base core plans show only 54 tandem-lift shafts vs. the 76 units described in Frank Lloyd Wright's building narrative?

SKETCH 1: The Illinois Tower; plan at base



The estimated 1956 building tenant populations located on office levels 1-528, at a density of 100 sq. ft./person net rentable area, would be about 123,000 persons. Since the advent of the word processor, centralized telephone equipment, Xerox machines, fax machines, and electronic mail, it takes far fewer clerical persons to staff a fully functioning office. Therefore, it is more likely that if the Illinois Office Tower were built today, the tenant floor densities would be in the 160-200 sq. ft./person range (about a 73,000-person population).* Even at today's population projections, we assume that the 15,000 space parking garage would have an estimate capacity of about 22,500 tenants (figured at 1.5 persons per automobile) and that the helicopters with a capacity of say 10 persons/helicopter, could deliver no more than another 2,000 persons to the job during the morning peak hour. This leaves about another 50,000 persons that must arrive at the site, probably via some form of rapid-transit system. The impact of such a system could vastly increase the lift handling capacity requirements during the morning up-peak period. However, in this analysis, we have assumed the group handling capacity requirement for a diversified-tenancy type of occupancy or 12% of each elevator group being moved during the a.m. peak 5 minutes.

Since the elevator design criteria is not specified, we have assumed that the building would have to meet the requirements for Class "A" space in order to be competitive. We have selected morning up-peak traffic average intervals of ≤30 seconds and times to destination of ≤150 seconds for all lift designs.

The quintuple-elevator car capacities have not been identified so we estimate that 3000-5000# units would be appropriate for the project. Even at these duties, the estimated 5-tandem car weight would be in excess of 35,000# unless the cars were constructed of aluminum. The 10,000# New York World Trade Center shuttles are the heaviest high-speed cars that have been built to date at 12,960#. The cars are equipped with 8 each, 3/4" diameter hoist ropes in order to achieve the mandated 10:1 safety factor.

The Mega High-Rise Lift Dilemma

Anytime a high-rise office tower exceeds about 60 stories in height it probably contains in excess of 1,000,000 sq. ft. of space and is usually serviced by 4 groups of single-deck lifts containing up to 8 elevators each. The dilemma on how to best serve additional building floors then arises. If we continue to try and service more upper floors with conventional zones of single-deck elevatoring solutions, the bottom floor areas are quickly reduced to nothing but elevator shafts, rendering the project uneconomical. There are at least 4 viable elevatoring solutions that can be employed to overcome this loss or rentable area and shaft encroachment dilemma:

1. Create upper sky lobbies so that the building tenants can express to and from the ground to the sky lobby and then transfer to "local" lift zones. The sky lobby/local solution partially overcomes the problem of increased shafts in the lower portions of the project because the lower and upper "local" zones can be stacked on top of one another.

   Sky lobby schemes can be either top-up (the local lifts are dispatched up from the sky lobby) or top-down (the local lifts are loaded at the sky lobby(ies) and then travel up and down from this floor).

   Sky lobby shuttles can be single-deck, 3500# to 10,000# units, double-deck lifts, car-car counterbalance lifts, and can have front and rear openings for ease in loading and unloading. The largest single-deck sky lobby shuttles utilized to date are the 46, 10,000# at 1600 FPM units installed in the twin 110-story New York World Trade Center Towers. The largest double-deck shuttles are the 14, 5000/5000# at 1400 and 1600 FPM elevators installed in the 110-story Chicago, Sears Tower Project. The Eiffel Tower and the Place de La Defense Projects in Paris, France both employ sky lobby, car-car counterbalance lifts for shuttling visitors to and from the upper-level observation decks. This same technology could be utilized for mega high-rise, sky lobby shuttle transport.

2. Provide more than 1 elevator car per shaft and thus reduce the number of lifts required in a given project. There are 2 methods of accomplishing this scheme. In 1931, dual independently operated elevators were installed in a 20-story Pittsburgh building. Each elevator was assigned a certain number of floors with the local unit assigned to the lower 10 floors while the upper, express unit served the top 10 levels. The average round-trip times were balanced so that the lower elevator would return to the lower terminal just ahead of the upper unit. The attendant-operated units were equipped with

blocking signals, much like a train system and were electrically interlocked so that the cars could only run in the same direction. Since the delay or failure of 1 car can adversely impact the other car even if the dispatching were coupled with the latest microprocessor controls, it is doubtful that this scheme has much of a future.

In 1932, the first double-deck (D.D.) lifts (2 tandem cabs stacked 1 above the other and fixed in the same frame) were installed in the New York City Subway Terminal Building. This "pure" double-deck scheme was an attempt to increase the group handling ability of the zone lifts by having each car only stop at alternate levels during peak traffic periods. In this way, it was expected that each double-deck lift could provide service to more zone floors in each elevator group while reducing the required number of lifts (and shafts) compared to conventional, single-deck (S.D.) elevatoring required to provide similar service in a given-size building. To date, a number of large office buildings have been constructed throughout the world utilizing the pure double solution and they seem to work quite well. The S.D. to D.D. ratio works out to about 70% or a 30% savings in the number of lifts required.

The St. Louis Gateway Arch actually employs 2 trains of multiple cab lifts installed in each inside leg for transporting visitors from the ground up to the top 630' observation platform. Each "train" is powered by a geared elevator hoist machine, contains 8 lifting pods that can accommodate 5 seated passengers each and operates at a speed of 340 FPM. The whole "train" is constructed of aluminum parts and weighs about 9000#. It is equipped with 9 each, 5/8" hoist ropes.

The Frank Lloyd Wright lift design for the Illinois Office Tower, utilizing a "pure" quintuple-deck lift strategy was a similar attempt to pack more than 1 lift/shaft and thus, reduce the number of lifts required.

3. Provide very large (or double deck) shuttle lifts that stop at say, every 10th level where the passengers discharge and then use side local lifts or escalators to shuttle up and down between the 5 interconnection levels between the skip stops. The 47-story Hong Kong Bank Project employs 23 skip-stop lobby shuttles serving 5 subzone sky lobbies with 60 escalators interconnecting the levels in between.

4. The ability to stack 50 or 60-story office building segments, each containing their own 4-5 groups of local lift systems and set them on top of one another is the key to designing mega high-rise office structures. Each connection point sky lobby located between the "stacked" structures can be serviced by its own set of dedicated shuttles or the sky lobbies can be

connected to each other by "feeder shuttles" so that multiple sky lobby transfers are required to get to the upper building sections.

The Quintuple-Deck Solution

The 76-car, pure quintuple-deck, elevatoring scheme, proposed by Frank Lloyd Wright for elevatoring the Illinois project is reviewed in this portion of the report.

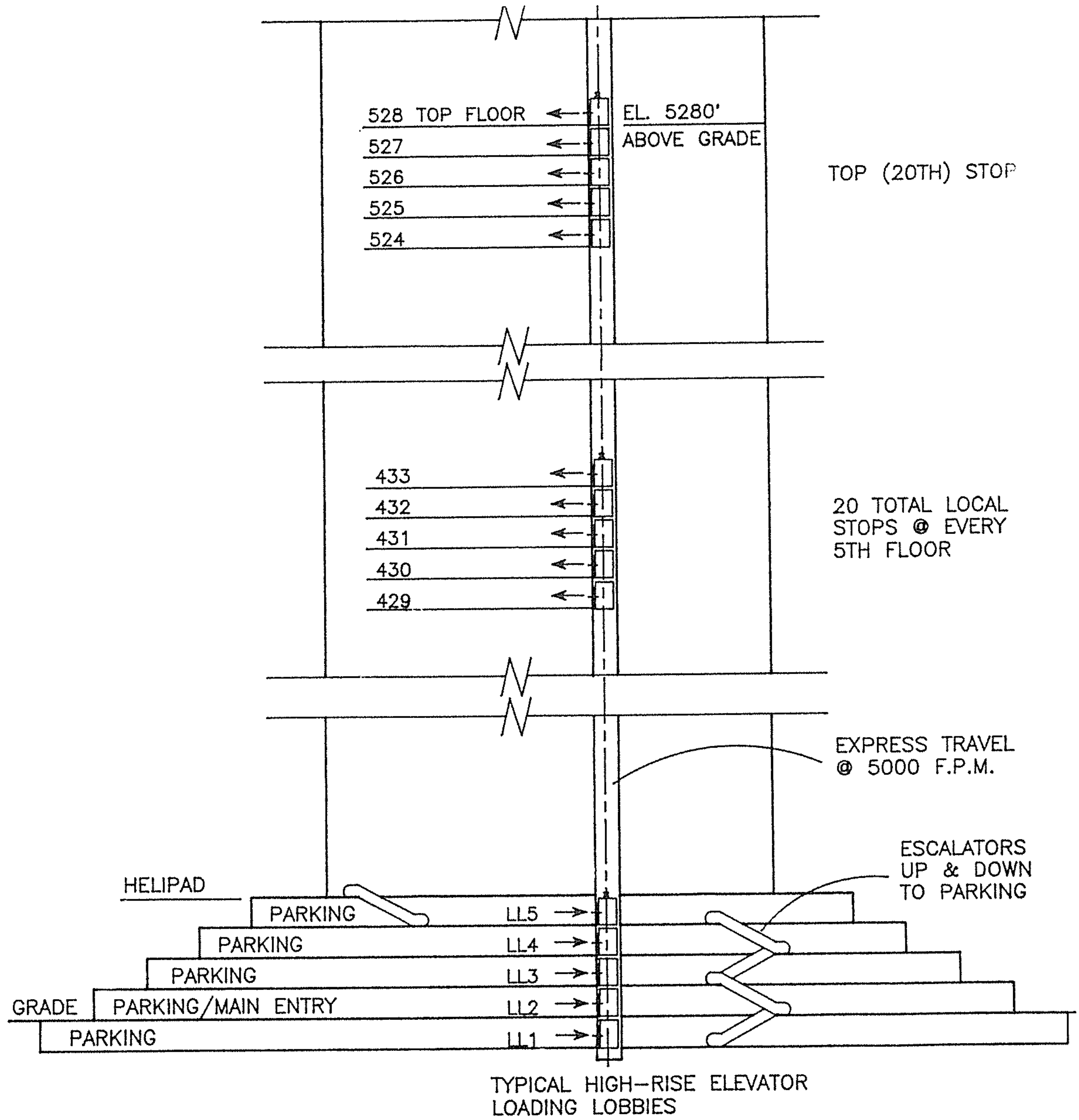
After loading in the base structure (see Sketch 2) during the morning up-peak condition, the lifts would make about 20 upper-level stops, while discharging their passengers at the appropriate floor, before returning to the base structure ready for another load. Because each lift is only programmed to stop at every 5th floor during the morning up-peak traffic flow, it is imperative that the passengers identify and board the appropriate lift cab so that they can alight at their destination floor without causing the lifts to make extra stops. As soon as the morning up-peak condition was completed, the elevators would be programmed to have the "trailing deck" (the bottom deck in the up-travel direction and the top deck in the down direction) respond to registered corridor calls. In this way, the "leading" decks are poised to pick up coincidental passengers. If built today, the lift dispatching would obviously be controlled by a microprocessor system with artificial-intelligence capabilities. Call destination (the Port system) registrations would likely be entered into the system by corridor digipads or voice-recognition sensors located at each upper-level elevator lobby.

Analysis Chart 1 indicates the results of our elevator study following the Frank Lloyd Wright's designs (except for the populations and floor heights) as closely as possible. Notice that the pure quintuple-deck solution takes 134 lifts to accomplish vs. the 76 units assumed by Frank Lloyd Wright. Perhaps this discrepancy can be explained by his assumption of a much-degraded group design criteria? On the other hand, he may have never actually performed an analysis and simply relied on rough estimates to determine the number of elevators required.

Physiological Problems Associated with High-Speed Lifts

When Frank Lloyd Wright revealed his plans for the Illinois Office Tower to the Chicago Daily News, which subsequentially published a story reviewing the proposed method of elevatoring the project, the paper immediately received comments from a number of airline pilots questioning the ability of 5000 FPM elevators to serve the project without causing ear-drum damage in the riding public. Airline pilots are well aware of the problems associated with too rapid a change in altitude. Apparently, the inner ear is susceptible to rapid changes in pressure associated with rapid ascents and descents that are experienced as aircraft change altitude. The same condition can affect elevator riders as speeds exceed about 2000 FPM or the vertical travel distances exceed about 1000'. Elderly persons, those with colds, flu and allergies, or the inability to rapidly clear ear passages are more at risk. Obviously, if the 5000 FPM, quintuple-deck elevators envisioned by Frank Lloyd Wright were to really rise and then descent about 5000' above sea level in 1 minute, the riders would probably experience considerable pain if they did not sufficiently "clear" their ears en route.

SKETCH 2: The Illinois Tower; Section at elevators



Think of the middle ear as a balloon that expands as interior pressure builds up during ascent and deflates during descent. As the airline cabin or elevator cab pressure decreases during ascent, the expanding air in the middle ear pushes the normal eustachian tube open letting the increased pressure escape down into the nasal passages until the pressure in the inner ear and the cabin, cab or final ascent level is equalized. However, during rapid descent, the passenger must consciously open the eustachian tube by swallowing, yawning, tensing muscles in the throat or by closing the mouth and pinching the nose closed and attempting to blow through the nose (Valsalva maneuver) to equalize the pressure. If either the ascent or descent (particularly, the descent) is too rapid and the pressure is not relieved, a painful condition called "Ear Block" can develop. Ear block can produce severe inner-ear pain and loss of hearing that can last from several hours to several days. If not treated, fluid can accumulate in the middle ear and become infected. In extreme cases, ear drum rupture can occur.

CHART 1
THE ILLINOIS
CHICAGO, ILLINOIS USA

ELEVATOR ANALYSIS SUMMARY

MARCH 1, 1992

DUTY	LEVELS SERVED	NET RENTABLE AREA (SQ. FT.)	FLOOR LOADING (SQ. FT./PERSON)	PROJECTED ZONE POPULATION (PERSONS)	INDIVIDUAL CAR LOAD (PERSONS/ DECK)	ROUND-TRIP TIME (SECONDS)	NUMBER OF ELEVATORS	5-MINUTE, A.M., UP-PEAK ELEVATORING: AVERAGE INTERVAL (SECONDS)	5-MINUTE, A.M., UP-PEAK ELEVATORING: GROUP HANDLING CAPACITY (PERSONS/ PERCENTAGE)	TIME TO DESTINATION (SECONDS)
LOW RISE - ZONE 1										
5000/5000# AT 1000 FPM	LL1-LL5, 1-110	1,750,000	160	10,937	26	445.5	15 *	29.7	1323/ 12.1%	126
MID LOW RISE - ZONE 2										
4000/4000# AT 3000 FPM	LL1-LL5, 111-220	1,362,667	170	8,016	20	459.9	15**	30.7	948/ 11.8%	131
MID RISE - ZONE 3										
4500/4500# AT 5000 FPM	LL1-LL5, 221-328	1,752,000	180	9,733	23	480.1	16	30.0	1150/ 11.8%	135
MID HIGH RISE - ZONE 4										
3000/3000# AT 5000 FPM	LL1-LL5, 329-428	850,000	190	4,474	11	436.5	15	29.1	567/ 12.7%	124
HIGH RISE - ZONE 5										
3000/3000# AT 5000 FPM	LL1-LL5, 429-528	369,000	200	1,845	5	397.5	13	30.6	245/ 13.3%	115

* 3 GROUPS OF 15 LIFTS EACH REQUIRED TO HANDLE THE 32,813 ZONE POPULATION
** 3 GROUPS OF 15 LIFTS EACH REQUIRED TO HANDLE THE 24,047 ZONE POPULATION

[ ] = MEETS THE DESIGN CRITERIA

SUGGESTED DESIGN CRITERIA

AVERAGE INTERVAL:	≤25-30 SECONDS
GROUP HANDLING CAPACITY:	≥12% OF ZONE POPULATION MOVED
POPULATION DENSITY -	
LOW RISE-ZONE 1:	160 SQ. FT./PERSON, N.R.A.
MID LOW RISE-ZONE 2:	170 SQ. FT./PERSON, N.R.A.
MID RISE-ZONE 3:	180 SQ. FT./PERSON, N.R.A.
MID HIGH RISE-ZONE 4:	190 SQ. FT./PERSON, N.R.A.
HIGH RISE-ZONE 5:	200 SQ. FT./PERSON, N.R.A.
AVERAGE TIME TO DESTINATION:	≤150 SECONDS
TENANCY TYPE:	DIVERSIFIED
MEASUREMENT PERIOD:	MORNING UP PEAK

Reportedly, the two 6000# at 1800 FPM observation elevators that travel 1346' above the ground express to the 103rd observation deck in the Chicago Sears Tower Building had to be slowed down to 1600 FPM in order to minimize the problems and litigation associated with ear block. Apparently, 1 of the building visitors suffered a broken ear drum after descending from the observation deck via the shuttles when they were running at the original contract speed.

In order to better understand the problem and suggest some solutions that may assist in designing future mega high-speed, high-travel lifts, it would be beneficial to review how the airlines handle the problem. Most jet aircraft cruise at altitudes of 30,000-40,000' above sea level, while the cabin is pressurized to a maximum of 8000' to protect the crew and passengers from discomfort. After takeoff, the cabin is pressurized at a nominal rate of 350 FPM, even though many jets climb at a rate of 3000-4000 FPM. This combination of pressurization and ascent speeds are apparently agreeable with the passengers and little discomfort is normally experienced. However, because of the difficulty some people have in clearing their eustachian tubes, the descent process is much-more complicated. During descent, the cabin is depressurized at a nominal rate of 350 FPM after the aircraft descends to 8000' while the actual descent is accomplished at about 500 FPM. At this rate, it would take about 23 minutes to repressure the cabin to sea level. Notice that the salient points here are that ascent can be accomplished very rapidly with little discomfort while descent must be carefully controlled. Have you ever noticed a young baby crying on an airplane during descent? The baby cannot consciously clear its ears so when the inner ear pressure builds up causing pain, the baby cries in response and voila! The pressure is naturally cleared.

The easiest solution to major high-rise, high-speed lift depressurization problems, as would likely be encountered in 100-story plus sky lobby shuttle elevators, would be to ascend at about 2000-3000 FPM and descend at no more than 500-800 FPM. Another method would be to install sky lobby breaks at every 75-100 stories so that passengers going to and from higher building floors and sky lobbies must transfer between sky lobby shuttles and get a chance to depressurize and repressurize en route to their final destination. This system of "feeder" shuttles is the reason that Ohbayashi Corporation indicated that it would take approximately 15 minutes for a person to go from the ground to the top floor in their proposed 500-story, 6669' tall Aeropolis 2001 tower planned for Tokyo Bay. The most-difficult solution would be to design a series of prepressurization locks or holding areas to be located at the top shuttle elevator terminal where the lift passengers are reacclimated before they would be allowed to board the lifts for the descent. Under this scenario, the elevator hoistways would have to be enclosed and pressurized along with the adjacent, preboard airlock. The advantage of this scheme is that it would permit the lift passengers to wait for the lifts in a prepressurization holding/waiting lock and then board the lifts for a very-rapid descent (speeds of 2000-3000 FPM would not be uncommon) to the grade exit level. This scheme would also permit the lifts to express to heights in excess of 200 stories without having to transfer between intermittent sky lobby shuttles (the feeder lift scheme) or to travel down at very slow speeds. The mega height/speed scheme also dramatically reduces the time it takes to reach the top floors and total passenger transit times.

The Future

Over the years, a number of mega-rise building projects (100 stories +) have been proposed for different parts of the world. In order to make these dreams a reality, we need some evolutionary changes in lift equipment in order to be able to handle a 100-150 story project. Future radical changes in elevator propulsion and guidance systems and repressurization need to be accomplished in order to make a 150-500 story project possible.

The evolutionary changes can be accomplished by the development of the following:

- o An ACV^{3}F 2000-2500 FPM gearless hoist machine with a 10,000# (double-deck) lifting capability.

o Wind displacement resistant hoistway equipment (trail cables, compensation cables, and pit equipment).

o Car top and bottom windage shrouds and plenum cabs.

o Voice recognition, call input sensors and call destination dispatching.

o On-board cab people sensors and lobby crowd detectors.

The revolutionary change possibilities:

o Development of high-speed (5000 FPM?), linear-induction motors either built into the car or counterweight. Power to be picked up from an electrified rail or inductive coupling in the hoistway.

o Repressurization air lock/cab systems.

o A high-speed, quiet rack and pinion lift or counterweight drive system.

o The ability to place multiple cars in dedicated-express lift shafts as traffic demands increase. This system requires the lifting pods to load and unload out of the hoistway and then move horizontally back into the shaft for vertical transport.

o A magnetic (repulsion) levitation (super cooled?) lift platform.

o A gravity shield to control the application of gravity to the lift platform (this will require a working model before a patent can be issued).

Conclusions

1. Assuming for a moment that quintuple-deck, 5000 FPM lifts were a possibility and the 528-story Illinois Office Tower only had a present population of 73,000 persons (5 upper-zone population), our analysis indicates that it takes 134 of the quintuple lifts to provide an acceptable level of service vs. the 76 units postulated by Frank Lloyd Wright.
2. The pure quintuple-deck elevatoring scheme might be practical if a 5000 FPM, tandem-car equipment was developed and the problems associated with ear block and call destination dispatching could be overcome. The 134+ cars associated with this scheme may consume a lot of space but when compared to the 250+ elevators required for any conventional double-deck/sky lobby plan, the idea has a lot of merit.
3. A more-practical solution to serving upper Zones 4 and 5 might be to elevator the spaces with conventional pure double-deck lifts moving up from sky lobbies created with quintuple-express shuttles.
4. The danger of ear block will hamper the ability to construct a mega high-rise project unless a way is found to repressurize descending passenger cabs.
5. Future changes in lift propulsion systems and multiple "lifting pod" systems could revolutionize the way we presently elevator high-rise buildings.