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ACCELERATING MOVING WALKWAY SYSTEMS

Technology Assessment

Engineering Research and Development Division
THE PORT AUTHORITY OF NY & NJ
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FINAL REPORT

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16. Abstract

Variable speed, Accelerating Moving Walkway Systems (AMWSs) represent the next evolutionary phase in a century of moving way transportation system development. AMWS(s) resemble conventional constant speed moving walks in appearance, but have the capability through changing treadway configuration to accelerate pedestrians to 4 to 5 times the conventional system speed. An assessment of the current state of AMWS technology indicates that there are five systems at various stages of hardware development and testing. Two systems are bi-directional loops using a treadway of intermeshing pallets. The remaining systems are one directional using treadways comprised of either laterally moving pallets, intermeshing leaves, or abutting rollers. Handrails are developed for only two systems, one employing multiple conventional handrails in series, and the other utilizing moving variable speed handgrips. Site adaptability of the systems varies with the system width and sub-grade depth installation envelope, as well as horizontal and vertical alignment adaptability. Furnishing and installation costs of the systems are relatively high, but their mechanical simplicity results in comparatively low operating expenses and energy use. A review of AMWS safety and human factors indicates, apriori, no significant reason why the systems cannot operate at levels of safety acceptable to the public, providing a specific safety program is followed.

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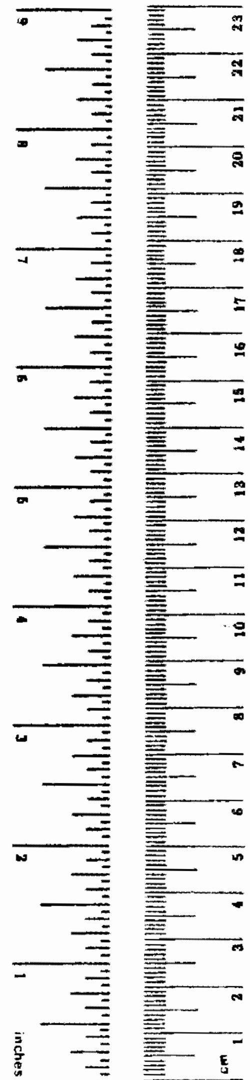
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F

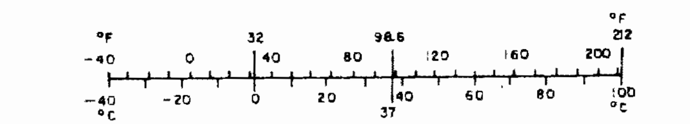


TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

Summary

A review of the available variable speed accelerating moving walkway system (AMWS) technology for the purpose of determining candidates for a public use demonstration indicates that there are currently five potential AMWS developers at, or near, the hardware prototype stage of development and testing. These five systems, in the approximate order of their development stage include: (1) the Speedaway system by Dunlop, (2) the TRAX system by the Regie Autonome de Transports Parisiens (RATP - Paris Transit Authority), (3) the Applied Physics Laboratory (APL) system by Johns Hopkins University, (4) the Boeing system by the Boeing Corporation, and (5) the Dean system by the Dean Research Corporation.

This report contains a general review of moving way transportation system technology development history, as well as an assessment of the five AMWSs listed above from the standpoints of (1) siting characteristics, (2) passenger service characteristics, (3) costs, (4) developer qualifications, and (5) system safety and human factors. The systems considered in the report vary in their dimensional envelopes, thus affecting their adaptability to site conditions which might typically be encountered in urban applications. Two of the systems are bi-directional, limiting their applications to locations where there is this type of traffic requirement as well as sufficient width. The three remaining systems are uni-directional but vary in alignment and sub-grade depth requirements. The performance of the various systems will depend on their dimensions, motion characteristics of treadway and handrails, and treadway and handrail materials and configuration. Initial user

tests show generally favorable acceptance of the available prototypes, but some performance modifications may be necessary to meet the requirements of an unlimited public use demonstration. Accelerating moving walkways are continuous service systems generally offering more favorable passenger service levels than vehicular transit for shorter distance applications.

Accelerating Moving Walkway System costs for fabrication and installation of initial production units are expected to be in the approximate range of about 50 to 100 per cent greater than conventional moving walkway systems, or about $1500 to $2400 per lineal foot $4920-$7870/m). Additional costs would be required for structural, architectural, and electrical system preparation of the site, and would vary significantly for at grade, or grade separated installations. Accelerating walkways are expected to require relatively little additional manpower for mechanical maintenance than conventional escalators and moving walks, and except for the premium for increased speed, operation and maintenance costs are expected to be consistent with the conventional systems.

The qualifications of the various developers to manufacture and install an AMWS unit for a public use demonstration, as well as to provide all the necessary logistic support for a demonstration, varies from well established manufacturers of moving way equipment to those with very limited experience in this field. However, it is expected that these deficiencies could be remedied through licensing arrangements and through the support of qualified consultants where necessary. A review of the safety and user human factors related to the available accelerating walkway prototypes and system components has established no apparent reason, apriori, why these systems cannot be operated at levels of safety acceptable to the public, but this assumes that a basic safety program is followed not only addressing equipment design, but instruction of passengers in the proper use of the system. A comparative summary outline of the system assessments follows in Table A.

TABLE A

ACCELERATING MOVING WALKWAY SYSTEMS

TECHNOLOGY ASSESSMENT - COMPARATIVE SUMMARY

	ITEM \ MODEL	DUNLOP SPEEDAWAY	RATP TRAX	JOHNS HOPKINS A.P.L.	BOEING	DEAN RESEARCH
1.	System Type and Current Status	One-directional, abutting pallet treadway; fully tested prototype, near production.	Two directional loop, intermeshing pallet treadways; partially tested full scale prototype.	One directional, intermeshing leaf treadway, partially tested, reduced scale prototype.	Two directional loop, intermeshing leaf treadway, reduced scale prototype under construction.	One directional, abutting roller treadway, prototype segment partially tested.
2.	Siting Characteristics	"S" shaped alignment, 30 ft. wide ends, 57 in. subgrade, level sites.	Linear 14-16 ft. width throughout, 7.4 ft. subgrade at ends, 20 in. on line, some grade and alignment variability.	Linear, 6 ft. approx. width throughout, 15-24 in. subgrade, some grade and alignment variability.	Linear, 14 ft. width throughout, above grade installation, some grade and alignment variability.	Installation envelope not defined, linear, 6 ft. approx. width, promising grade and alignment variability.
3.	Passenger Service Characteristics (all systems continuous)	Motions treadway and handrail should be acceptable to public based on tests.	Motions treadway acceptable based on tests, handrail undergoing tests.	Motions treadway acceptable based on tests, handrail designed but not tested	No testing at time of report.	Treadway motions reported as acceptable based on limited tests.
4.	Estimated Total Costs (Equipment, Site Construction and Installation) per lineal foot or route installed, based on 1000 ft: grade	$3474/LF	$4430/LF	$2560/LF	$3030/LF	$2860/LF
	bridge	$4194/LF	$5650/LF	$3440/LF	$4250/LF	$3740/LF
	subway	$5864/LF	$7020/LF	$4530/LF	$5620/LF	$4830/LF
5.	Developer Qualifications	Fully qualified moving way system manufacturer.	U.S. licensee, possible consultant assistance required.	U.S. licensee, possible consultant assistance required.	Qualified transportation system manufacturer, possible consultant assistance required, moving way passenger systems.	Industrial conveyor manufacturer, possible consultant assistance required, moving way passenger systems.
6.	Safety and Human Factors Potential Problem Areas	Handrail proximity at wide entrance and exit, multiple handrails, pallet movement beneath balustrade.	Bunching, treadway meshing, handrail synchronicity with treadway, handrail detailing under test.	Bunching, treadway meshing, handrail not tested.	Bunching, treadway meshing, handrail detailing not known or tested.	Treadway rippling, vibration and other affects, handrail detailing not known or tested.

1.0 MOVING WAY TRANSPORTATION SYSTEM DEVELOPMENT

Accelerating, variable speed mechanical moving walkways represent the next phase of development in the century of evolution of moving way system technology. Conventional single speed mechanical walkways have been installed in many airports, transit systems, and other urban activity centers, for the purpose of extending the effective trip range of the pedestrian. Improved pedestrian transportation is a widely recognized urban development objective which is considered to have significant societal benefits which are identified in more detail in Report D of the Demonstration Project study series, Accelerating Moving Walkway Systems -- Market, Attributes, Applications, Benefits. Increasing the number of pedestrian trips and pedestrian trip distances would reduce the atmospheric, noise, and visual pollution caused by vehicular transportation, and improve the effectiveness and economic utility or urban core areas and activity centers.

The current conventional moving walkway technology speed limitations dictated by the requirements for a safe and comfortable human boarding and exit speed are an inherent constraint which has limited the application of these systems to horizontal movement problems in trip ranges encountered in many urban centers. System speeds are about half normal walking speeds and the concomitant trip time penalty for riders who choose to stand, rather than walk on the systems, has resulted in commonly accepted maximum system lengths of about 600 feet (183 M.). The objective of Accelerating Moving Walkway System (AMWS) technology development is to produce a system which will operate with a line speed about twice the speed of walking, providing a time and human energy saving advantage which will extend the effective moving way system range, increasing the applicability to pedestrian movement problems and potentially competing with certain types of vehicular transit systems for short range applications. Boarding and exiting speeds for variable speed systems would be the same as conventional escalator and moving walks. The continuous service no waiting aspect of moving way transit systems produces travel time advantages for short trips over vehicular systems with batch loading and operating on typical headways.

The purpose of this Technology Assessment report is to determine the current status of development of AMWS technology, to establish potential candidates for a public demonstration, to establish definitive cost and operational data, as well as user acceptability and safety. AMWS(s) are currently in all stages of development ranging from theoretical concepts which have not been translated into any form of mechanical design, to systems that have been advanced to prototype hardware limited to experimental use, or in two cases, to full scale near production models. The complete design details and possible design revisions of all systems are not yet known, limiting the full determination of their potential operating characteristics and the specific evaluation of safety and human factors. However, sufficient detail is available to establish principles of operation, system dimensional envelope, probable equipment operating characteristics, approximate installation costs, and other similar data necessary to evaluate the respective system designs.

Site adaptability, an important factor affecting the general use of AMWS(s) in both new and existing installations, varies considerably between the system with some designs forming a single linear configuration similar to existing moving way systems, and other designs forming loop or "S" shaped configurations. Production capabilities of AMWS developers likewise range from well-established manufacturers in the moving way transportation industry who have the resources and experience to supply, install and logistically support a demonstration AMWS with high levels of confidence for the sponsor, to individuals without industrial backing who would be incapable of manufacturing and testing satisfactory AMWS hardware within the Demonstration Project time frame.

This report establishes the current state-of-the-art of AMWS technology, the current development status of possible candidates for a public demonstration, and summarizes the available operating characteristics and performance, design details, dimensions, equipment data and other information necessary to describe the respective candidate systems. System safety and human factors, a primary demonstration consideration, is the subject of a separate project study, Report C -- Accelerating Moving Walkway System Safety and Human Factors.

This report is comprised of a general discussion and classification of moving way transportation systems, a brief history of moving way system development, description of conventional single speed systems and comparative summaries and assessments of the five AMWS systems currently at, or near, the hardware stage of development.

1.1 Moving Way Transportation System Classifications

Moving way tramsportation systems are carriers providing continuous service with passengers boarding the moving system rather than batch boarding of stopped vehicles. The advantages of continuous service systems are high passenger capacities relative to system speed, and the elimination of waiting and batching loading times. Other advantages include mechanical simplicity as compared to the equipment and control sophistication required for automated guideway transit, and reduced manpower requirements as compared to non-automated vehicular systems using drivers. Escalators and moving walks are examples of constant speed pallet and continuous belt moving way systems in common use for passenger transportation. A wide variety of continuous movement systems utilizing pallets, belts, rollers, draglines, and other conveying methods are in use for goods movement in industrial applications.

Despite many advantages of continuous service systems, they are inherently constrained to a speed that is acceptable for the general population to board and exit from the system safely and conveniently. Escalator and moving walk speeds in the United States are governed by the American National Standards Institute Code, which sets maximum speeds for escalators at 120 fpm (37 mpm) and level moving walks at 180 fpm (55 mpm)* [1]. Inclined moving walks must operate at lower speeds depending on their slope. In actual practice in the United States many escalators operate at 90 fpm (27 mpm) and moving walks at 120 fpm. Escalator and moving walk operating speeds in Europe are

*Average normal human walking speed is 270 fpm (82 mpm).

higher than the United States norm, with moving walks in the Paris Metro subway system operating at 164 fpm (50 mpm) and escalators in the Leningrad subway reported at 180 fpm (55 mpm). A study of the use of a variable speed escalator by the London Transport system showed that optimal passenger capacity was attained at a speed of 145 fpm (44 mpm) and that further increases in speed did not result in increases in capacity [2]. Photographic observation of pedestrians boarding escalators showed that system utilization was related to individual human performance, including perception and reaction capabilities, psychological attitudes towards crowding, presence of baggage or other carried articles, and in addition, traffic conditions. The accelerating variable speed moving walkway would have entry speeds set at accepted norms, and then gradually accelerate passengers to higher line speeds, approximately double the speed of walking. Prior to exiting, the system would gradually decelerate, reaching normal alighting speed at the exit.

Variable speed moving transportation systems including accelerating moving walkways have been proposed in a number of different configurations, but only a few have reached the operating prototype or "hardware" stage of development. Table 1.1 following summarizes the major accelerating system classifications.

Multiple Belt Systems - first proposed, built and operated in the ninteenth century, and still commonly used at world's fairs and amusement parks where large volumes of passengers must be continuously processed, these multi-stage systems overcome the restraint imposed by human boarding speed limits by use of a slower speed moving walk to

TABLE 1 – AMWS CLASSIFICATIONS

MULTIPLE BELT SYSTEMS			
PARALLEL BELTS - RUNNING CONTIGUOUSLY	MULTIPLE BELTS - LINEAR ARRAY	EXPANDABLE BELT SYSTEM (LINEAR ACCELERATOR BY PFEIFFER & CANDELLA)	PLATFORMS - RUNNING CONTINUOUSLY (SPEERS, RETTIG, STORER, SILSBEE)

PALLET SYSTEMS....FORWARD AND CROSS SLIDE			
RECTANGULAR PALLETS (MODIFIED) (DUNLOP SPEEDAWAY)	SCIMITAR PAVEMENT (NRDC)	LENTICULAR PALLETS (GRAVITY ACCELERATOR)	LINEAR ARRAY (OVERLAPPING PALLETS) (CRESTWALK)

EXPANDABLE MESH SYSTEMS		ROLLER SYSTEMS	
EXPANDABLE DIAMOND MESH SYSTEM (AYRE'S SYSTEM)	EXPANDABLE MESH WITH OVERLAPPING PLATES (TRANS 18)	DEAN RESEARCH PENN-FLEX	

OVERLAPPING LEAF OR PLATE SYSTEMS			
ACCELERATING WALKWAY (APL SYSTEM)	BOEING	SYSTEM 'TRAX'	ACCELERATING BELT (GEORGIA INSTITUTE OF TECHNOLOGY)

OTHER SYSTEMS			
ROTATING DISC ACCELERATOR (KRAUSS MAFFEI, LEBOULIS, TELECANAPE)	OSCILLATING ELECTRIC APRON (JACKSON & MORELAND)	EPICYCLOIDAL DISCS (VIETORS)	PARISTALTIC TRAVELLING WAVE (CRANFIELD)

board a sequence of one or more progressively higher speed stages. In some installations the higher speed stage provides seating [3]. Passenger disembarking from the system is accomplished by walking through progressively slower speed stages until the safe exit speed stage is reached [4].

Variations of the multiple belt concept have been proposed to provide a continuous linear system similar to existing conventional moving walkway rather than using parallel units. Jackson and Moreland, in connection with a consulting study of a system of elevated moving walkways for the City of Boston, proposed a linear array of conventional moving walks in series, with progressively higher speeds to attain line speeds several times the entry speed [5]. The consultant recommended thorough testing of the proposed system to determine user adaptability to multiple in line speed changes, as well as to assess the safety effectiveness of equipment details such as combplates and higher speed handrails. Candella [6] and Pfieffer proposed linear belt systems in which expansion of the belt surface would occur to produce acceleration. Candella proposed a belt take up drum, somewhat comparable to a window shade cylinder, which would deploy added belt length in the accelerating section, and take it up in the deceleration section. Pfieffer proposed a sequence of intermeshing belts running at increasing speeds which also would reportedly expand in the accelerating sections. The problem with these systems is that any treadway belt which is required to turn around a drum or cylinder with the necessary radius, forms a potentially dangerous surface discontinuity which could trip or entrap passengers. Other multiple platform systems developed include the following:

Pallet Systems - Variable speed walkway systems using pallets have the advantage that the treadway surface is solid beneath the passengers' feet, avoiding problems that may be associated with the expansion of the treadway surface in the acceleration section of the walkway, and its contraction in the deceleration zone. The contraction of the walkway surface offers potential crowding or so called bunching hazards should passengers move in too close in proximity to each other as the walkway surface decreases. The Dunlop Speedaway system, which is advanced to the production model stage of development, is an example of the pallet design. Factory prototype units of the Speedaway have been successfully used by relatively large numbers of persons of varying ages and physical capabilities [7]. The Dunlop system is described in greater detail in Section 2.1 of the report. Variations of the pallet concept have been proposed which employ pallets shaped in curved configurations rather than the trapezoidal pallet used in the Dunlop system. Other pallet concepts include the "Scimitar" pavement system which would use pallets shaped in interlocking curved sections having the advantage that the system could be aligned in a horizontal curve or loop, and a lenticular pallet system in which the treadway is comprised of alternate convex and concave platforms, which can also be used in curved alignments [8].

Roller Systems - Would employ variable speed rollers in series similar to the industrial conveyors used to move goods. The Dean Research

Corporation has built a small section prototype of a roller system, employing 1 inch (25.4 mm) diameter rollers, which is described in greater detail in Section 2.6 of the report. The Penn Flex Corporation proposed a similar concept using grooved rollers in series.

Overlapping Leaf or Plate Systems - Consist either of grooved intermeshing pallets, which slide over each other to produce expansion or contraction of the treadway surface, or angled intermeshing leaves, whose deployment angles determine treadway changes [9]. The Johns Hopkins University, Applied Physics Laboratory (APL) built and has successfully operated a prototype system employing the intermeshing leaf principle, which is discussed in greater detail in report Section 2.3. The Regie Autonome des Transports Parisiens (RATP - Paris Transit Authority) has built and successfully operated a prototype of a grooved pallet system called TRAX, which is described in report Section 2.2. The Boeing Corporation has a similar concept under development which is illustrated in Section 2.5.

Other Systems - There are many other accelerating variable speed walkway proposals which have not progressed beyond the conceptual phase, in a few cases because suitable treadway materials or mechanical components are not available. Some systems are considered to raise significant human factors problems or have doubtful applications which mitigate against further development. Some other AMWS concepts of interest are the Rotating Disc Accelerator by Krauss-Maffei, the Oscillating Electric Apron proposed by Jackson and Moreland, the Epicycloidal Disc System of Vietors, the Paristaltic Travelling Wave proposed by the Cranfield Institute of Technology, and Mann's Crestwalk [Ibid. 3, 6, 8].

The Krauss-Maffei proposal consists of a constant high speed (13 mph) moving belt which is boarded and exited from a rotating disc platform. Passengers enter an inner disc at ground level which serves as a rotary lift carrying them to the inside of a rotating disc to which they transfer and on which they walk to the periphery for transfer at synchronous speed to the high speed belt. A small scale working model of the system has been built. The oscillating elastic apron of Jackson and Moreland uses constant acceleration to accelerate passengers from zero to the main belt speed. The accelerator consists of an elastic apron using a double array of longitudinal intermeshing tread ribs or slats. One set of ribs rises and moves forward and then drops down to return, the motion is then picked up by the next set of ribs to move the passenger forward. The passenger speed increases in proportion to the distance from the boarding point. Vietors patented a proposal in 1898 for a system using a disc shaped platform based on the kinematic law of the cycloid, which is that the path traced by a point on the circumference of another disc is that of an epicycloid. The principle would be utilized to load passengers by the rotating disc between a central stationary circular platform and a high speed moving annualr platform. In the Cranfield Institute of Technology Peristalic system proposal, the propulsion is provided by traveling wave motion. A flexible tube is nipped by a roller to form a seal. When air is pumped into the tube at one end, the resulting pressure wave propels a series of roller mounted platforms or pallets. Mann's Crestwalk proposal is based on traveling velocity waves which permit a conveyor to be boarded or left at any point. This effect is produced by moving each platform or pallet forward at a regular cycle of high and low speeds, but with a slight phase difference between each platform. A passenger by walking forward may maintain conveyance by stepping on the crests or high speed phases, or by standing, decelerate to a low speed phase for alighting.

1.2 History of Moving Way Transportation Systems

Moving way transportation has undergone over a century of development. (See chronology, Appendix.) Chronologically, the escalator was invented first, but it was the moving walk that was first built and opened for public use. The history of moving way transportation began in 1859 when an American inventor names Nathan Ames was issued a patent for what he called Revolving Stairs. This primitive concept for an escalator, which was never built, consisted of a series of steps linked together to produce a continuous moving stairway. In 1892, a patent for an "Inclined Elevator" was granted to Jesse W. Reno for what was to become the first operational antecedent of the escalator. Reno's "Inclined Elevator", as it was called, was a continuous moving ramp with a sloping treadway surface formed by a series of boards or pallets guided and supported by rails. Board surfaces were covered with small rubber cleats running parallel to the direction of travel to prevent passengers from slipping on the inclined treadway, which was sloped at an angle of 30 degrees. To aid in smoothing the transition from moving to stationary surfaces, and to prevent foreign objects from jamming under the endplate, comb-like prongs were mounted at the ends of the ramp. These prongs ran between the rubber cleats of each board in the chain. Great care was also taken to shield all moving parts in order that they would not come in contact with passengers' clothing. The inclined elevator was equipped with two handrails, at least one of which moved with the conveyor. The movable handrails were continuous chains covered with flexible rubber and a soft pile covering.

Though the patent for the "Inclined Elevator" was registered in the spring of 1892, it was not until the fall of 1896 that the first inclined elevator was installed at the Old Iron Pier in Coney Island, New York. Thereafter, the Reno Inclined Elevator was sold in the United States and Europe, and by the year 1900, a number of them were installed in some large department stores in New York City and Philadelphia. Five units were also constructed for the Paris Exposition of 1900, and another was installed in the Crystal Palace at Sydenham, England. The general acceptance of the Inclined Elevator was virtually guaranteed in 1900 when one hundred of them were ordered by the Manhattan Elevated Railroad Company in New York City. The first of these was installed at the Third Avenue and 59th Street Station, and were eventually constructed at every principal station of the elevated railroad (EL). They remained in service until the "EL" was demolished in 1955.

It is curious to note that another patent for an inclined elevator was issued in 1892 to a George H. Wheeler for a "Moving Stairway". This stairway was similar to the Reno invention, but with the exception that the treadway surface was formed of individual stairs. However, Wheeler's invention was never built, and the patent was sold to Charles D. Seeberger in 1898. Mr. Seeberger then joined the Otis Elevator Company, and in 1899 the first two prototypes of the step-type escalator were constructed, with the first sold for commercial use in 1901. In its early years of development the step-type escalator was not very successful. For many years thereafter, the only two markets for escalators were department stores and public transportation. Between the years of

1900 and 1920, acceptance of the escalator was slow with only an average of seventeen units sold worldwide per year. From 1900 to 1911, Otis and Reno were the only companies in the world building escalators and inclined elevators. Then in 1911, the two companies were merged when the Reno Company was acquired by Otis.

From that time until 1920, both the Otis step-type and the Reno cleat-incline type excalators were sold in almost equal quantities. However, in the year 1920, the escalator was completely redesigned and the best features of the step-type escalator and cleat-incline type elevator were combined. Among the design features which evolved from the combination of features from the two escalator types, plus experience gained from their operation were the following:

- Combplates - Before 1920, the steps at the floor landings of the step-type escalator ran beneath a diagonal transition section or "shunt". This virtually pushed passengers off the escalator, forcing them to take an awkward sidewise step to the landing with one foot while the other foot was still moving forward on the step. This required a high degree of concentration and agility. The Reno inclined ramp used comb-like prongs, twelve to sixteen inches long, meshing with cleats on the treadway. This arrangement eliminated the sideways step at the exit, but passengers disliked the jolting affect of the long prongs and tended instead to either jump off, or take a large step over the prongs, frequently causing them to fall. These problems were solved by creating a combplate with much shorter prongs which were made with grooves on the escalator step, much like present day designs.

- Speeds - Originally, the cleat-incline elevator and the step-type escalator were driven at speeds that varied between 80 and 100 fpm (24-31 mpm). In 1920, the speed was standardized at 90 feet per minute (27 mpm). Currently, speeds of 90 fpm and 120 fpm are in common use in the U.S.A.
- Handrails - The handrails of the first inclined escalator were chains covered with solid rubber and guided by a lubricated steel channel. This lubrication soiled passenger's hands, gloves, or clothing and the design was abandoned in favor of the one used on the step-type escalator, which consisted of a tension-driven rubber and canvas handrail that was guided by a simple unlubricated channel. Sometime later, pinch-proof handrails were inaugurated in order to prevent passengers' fingers from getting caught under them.

Further improvements made in the escalator in the years following 1920 were as follows:

- Steps - Until the 1930's, escalator steps were constructed of wood. After that time, the wooden steps were abandoned in favor of the now common, narrow-gauge cleat-type diecast metal step. The narrow gauge was introduced in order to keep high-heels and other objects from snagging or lodging in the cleats and wider spaced combplate.
- Extended Balustrade - An important improvement in escalator design occurred when the balustrade and handrails were extended beyong the comb-plate. This simple design change improved escalator safety by encouraging passengers to grasp the handrail and adjust to the speed of the unit before stepping onto the moving surface, and also to the

stationary pavement when exiting. The balustrade and handrail extension also moved the return, or point at which the handrail entered the balustrade, away from where it could entrap passenger clothing or hands.

Moving Walkways - evolved concurrently with the development of escalators. The first recorded proposal for a continuous moving platform was made in the year 1874 by an American engineer named Speer. The system, which was proposed for lower Manhattan, was an elevated loop consisting of continuously moving platforms running at a speed of about 15 mph (25 kmph), boarded from motorized "cabins" that picked passengers up from a standstill position at station platforms. From 1875 to 1900, a host of proposals and patents for moving platforms were recorded in the United States and Europe, but of these only three were built, the 1893 Chicago Columbian Exposition, the 1896 Berlin Industrial Exposition, and the 1900 Paris Exposition. The Columbian Exposition installation was a 2-speed system with platforms operating at speeds of 264 and 528 feet per minute (80.5, 161 mpm), with the slower platform being used for boarding and exiting. The system was laid out on a mile long oval path in Jackson Park, near Chicago. The fast platform featured transverse seats, while the slow one was equipped only with handposts installed at 12 foot (3.66 meter) intervals. Their function was to aid passengers in getting on and off the platform. The system erected in the Berlin Industrial Exposition in 1896 was almost identical in principal of operation and construction to the one at the Columbian Exposition.

Reno inclined elevator - Paris Exposition, 1900.

The moving platform installed at the 1900 Paris Exposition, photo illustrates low speed boarding and exiting stage at right, higher speed stage at left.

FIGURE 1.1

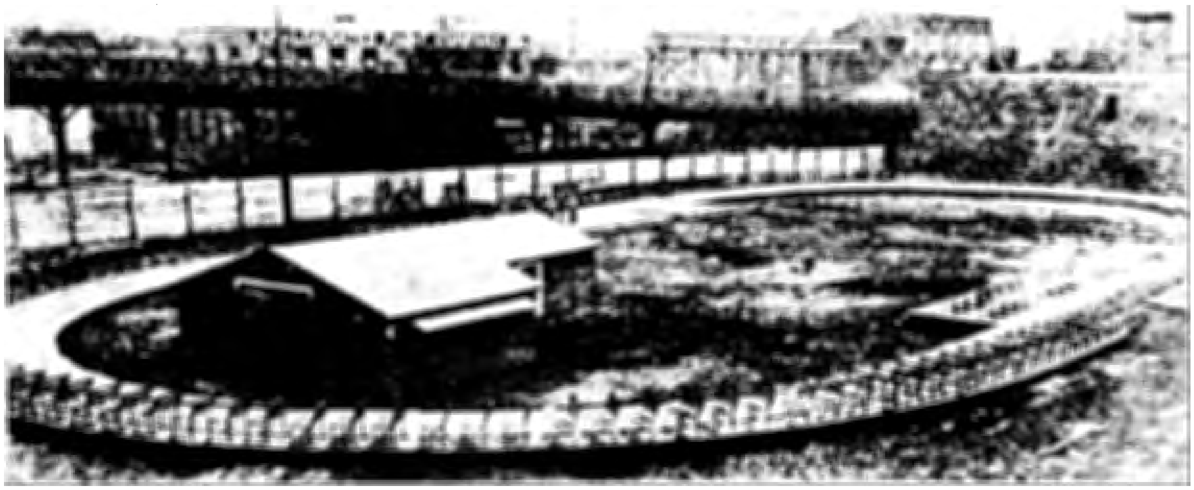
The Paris Exposition installation was one of the largest and most successful of the earlier systems, and the first example of an accelerated moving walkway system since there were no seats on the high speed section. The moving platforms were similar to those at the Columbian Exposition in 1893 in that they were a series of connected flat trucks continuously moving in parallel and contiguous paths, but they travelled at 196.8 and 393 feet per minute (60, 120 mpm). Its total length was about 2 miles (3.36 kilometers). One of the major reasons that this system was considered to be such a great success was its excellent safety record. During the seven months of its operation, it carried 6 1/2 million passengers with a total of only 40 minor accidents reported.

In the fall of 1904, a group of leading railroad officials put forth the idea of constructing a moving platform under 34th Street, New York City, which was to run crosstown between First and Ninth Avenues. The system was to have four platforms, three running continuously at 264, 528, and 792 feet per minute (80,161,242 mpm), and a fourth auxillary platform running at 264 fpm (81 mpm) only during off hours when the other platforms would be shut down for inspection and maintenance. The fastest platform of the series was to be fitted with transverse seats. The proposal was widely promoted and recommended, but due to objections of the Rapid Transit Commission at the time, it was never accepted.

In 1905, Adkins and Lewis, two British engineers, introduced the concept of using a system of variable-pitch screws to continuously drive a system of individual four-seat cars. These cars were to travel at 176 feet per minute (54 mpm) through the station in order to allow passengers to board and disembark and then accelerate to 1320 feet per minute (412 mpm) between stations. The system, which was called the Never-Stop Railway, was constructed and put into operation at the British Empire Exposition in Wembley, England, in 1925. The railway operated successfully for two seasons during which time it carried two million passengers without a single accident. Moreover, it ran every day for six months without a mechanical breakdown.

During the period 1905 to 1939 there were only two reported proposals for moving way systems. One was for a moving platform to run under 42nd Street in New York City from Grand Central to Pennsylvania Stations, and the other was the Biway Underground Rail System. The 42nd Street proposal was to replace the existing subway shuttle service. The speeds and proposed configuration was similar in many respects to the 34th Street proposal of 1904, with the exception of the fourth standby walkway. One interesting difference between the two proposals was the intention to power the 34th Street system with linear induction motors, rather than conventional motors. This would have required less depth in subway construction because of the horizontal plane of the linear induction motor. For reasons not known, the system was never constructed, although a complete demonstration unit was built on a Jersey City lot. (Figure 1.2)

In 1935 the Westinghouse Electric Corporation proposed a two stage moving way system called the Biway Underground Rail System. The high speed or express platform was to move continuously at 1320



Full scale model in Jersey City of a 1924 Putnam Proposal for a three stage continuous loop system to replace the N.Y.C. Times Square Shuttle. Seats positioned on the high speed section.

The General Motors two stage conveyor system of the type used at 1939 and 1964 World's Fair Exhibits, New York City.

FIGURE 1.2

fpm (403 mpm) and be fitted with transverse seats. The local or transfer platform was to vary in speed from zero, the boarding speed to the express platform speed of 1320 fpm. Boarding and exiting of the system was "pulsed" using automatically controlled gates which would allow entry to the local stage when the system was stopped and entry and exit from the high speed express section when the local section was in operation. Although the costs to run this system were estimated to be much less than those of running an ordinary subway system, the idea never reached fruition.

In 1939, the General Motors Building Futurama Exhibit at the New York World's Fair was equipped with a conveyor system that transported visitors through a portion of the exhibit on a continuously moving platform of seats. Passengers boarded this moving conveyor from a continuously moving horizontal loading platform or moving walk. In order to get a seat on the moving conveyor, passengers boarded the moving walk from a stationary platform and disembarked from it on to the moving conveyor which was running alongside the moving walk at precisely the same speed.

An innovative aspect of the system was its circular unloading platform. It was approximately 32.8 feet (10 m) in diameter and it was surfaced with continuous, concentric aluminum cleats. The edge of the unloading platform came into contact with the moving conveyor and rotated at the same speed as the conveyor. The unloading platform also came into contact with a stationary platform that had combplates on it which meshed with the concentric cleats of the unloading platform. To exit from the exhibit, passengers left their seats on the moving conveyor, stepped onto the unloading platform, rode it around to the stationary platform and stepped off onto it.

<u>Current Conventional Moving Walkway Systems</u> - fall into two categories, those with a treadway consisting of grooved, continuous rubber belt, and the pallet type with a treadway comprised of a series of grooved metal pallets similar to an escalator. Belt systems were introduced in 1952 when the first continuously moving rubber belt used for the transportation of people was installed in the B. F. Goodrich Company exhibit at the Chicago Museum of Science and Industry. It was a smooth belt, 36 inches (0.9 meters) wide that travelled at a speed of approximately 50 feet per minute (5 mpm). It moved by sliding along on a polished maple bed and had handrails that moved at the same speed as the belt. The Goodyear Tire and Rubber Company in conjunction with the Stephens-Adamson Manufacturing Company introduced a belt system that was to be used as a loading stage for the proposed Carveyor System. This belt differed from the Goodrich belt in that it ran on rollers to reduce friction losses, rather than on a flat slider bed.

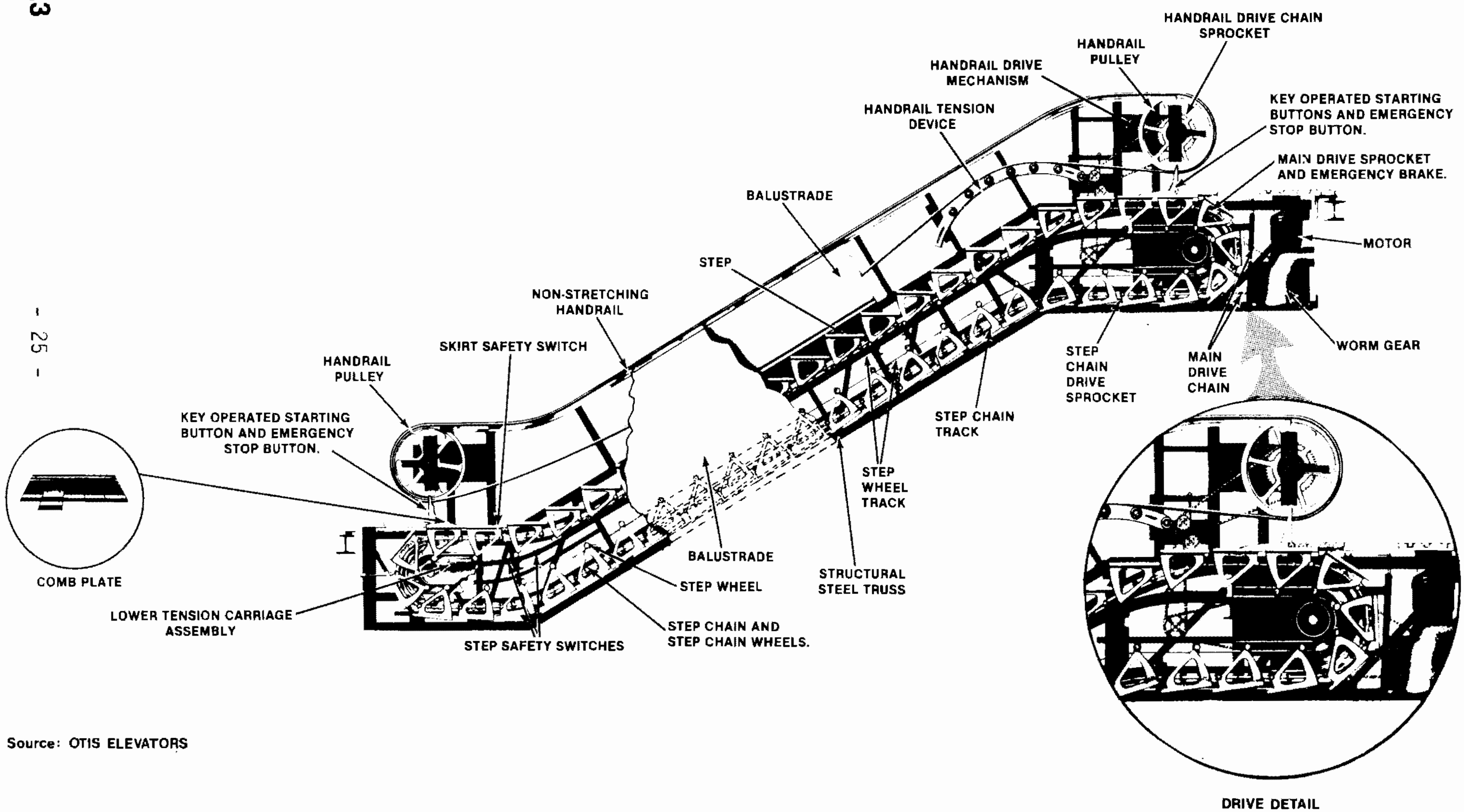
Another belt system, the Hewitt-Robins Glide Ride, was installed in the Love Field Airport Terminal Building, Dallas, Texas in 1958. The surface of this moving walk consisted of a continuous, smooth rubber belt which rode over individual, flat pallets that were linked together. In this system, the pallets supported the load of the passenger, and the smooth rubber belt simply covered the pallets and the gaps between them. Whether it was due to the lack of a suitable safety code at the time, or just an engineering oversight, the system did not include combplates at the ends of the moving belts. The end-plates were flat, scraper type blades under which the smooth belt disappeared. Foreign matter and articles of clothing could lodge between the end-plates and the belt. In 1960, this end-plate design contributed to the cause of a tragic accident. A little girl sitting on the belt was strangled by her clothing when it became trapped between the belt and the end-plate. In subsequent designs, the entrapment hazards created by the smooth-belt was significantly reduced by using grooved belts combed by a combplate at belt ends. Despite the tragic experience with the airport installation, the Glide Ride had innovative features in that it could follow the contours of a curve, making possible the return of the belt to serve as a walk in the opposite direction.

1.3 The Modern Escalator

The features of the modern escalator are described in this section for purposes of later comparison with accelerating walkways. Current conventional moving walkways are similar in most respects to the escalator. Externally, all that can be seen of a modern escalator is its continually moving steps and handrails, but beneath these steps and the sides of the balustrade enclosure is a relatively complex driving mechanism. The operational components in an escalator can be categorized into three functional drive systems; main, step, and handrail. (See Figure 1.1). The main driving mechanism is comprised of the escalator motor, worm gear, main drive sprocket and driving chain. The handrail and step drives are connected to the main drive sprocket. The handrail consists of a continuous hard neoprene rubber loop, tensioned and carried over pulleys at both ends of the escalator. Escalator steps are linked together in a continuous loop by the slip chain which is also connected to the main drive mechanism. Each step is fitted with step wheels, which are supported and guided by running tracks. All of these components are mounted on a steel truss that supports the entire load of the escalator and its passengers. The main drive motor usually is a three-phase induction motor in the 25 to 35 horsepower range, depending on the width and rise of the escalator. Steps are normally fabricated of cast, grooved aluminum alloy riding on two pairs of hard rubber-tired wheels. Each wheel rolls on steel tracks forming the path in which the steps and connecting step chains move around the escalator. A second pair of wheels is mounted at the bottom of the curved riser

FIGURE 1.3

A TYPICAL ESCALATOR



Source: OTIS ELEVATORS

of the step, also running on a track which sets the height at which the step rides at different points in its travel. The continuous, steel step chains that draw the steps up or down the incline and around the return also have roller wheels on them riding in tracks to provide for smooth, quiet running. Escalator handrails are fabricated of hard neoprene rubber on a fabric cord body with steel tape or steel wire running longitudinally through it. They are drawn by friction contact over pulleys at the lower and upper landings of the escalator and slide on guides mounted on top of the balustrades. Power to drive the handrails is provided by the upper handrail pulley connecting with the handrail drive sprockets, drive chain and main escalator drive, which results in the handrail operating at a synchronous speed with the steps.

Every escalator or moving walk must be provided with an electrically released mechanically applied brake capable of stopping and holding the treadway at rated load. These brakes must automatically stop and hold the treadway when power to the drive motor fails or when any other safety device is activated. In cases where the drive mechanism is connected to the main drive shaft by a chain, and where there is a brake on the main drive shaft, it is required that there be a device that will activate that brake if the main drive chain of either step chain fails. The same is true for a failure of the connecting link between steps or pallets.

1.4 Manufacturers' Survey

A manufacturers' survey was conducted as the initial phase of the assessment of Accelerating Moving Walkway System technology. The purposes of the survey were to inform the moving way system industry of the AMWS demonstration program, obtain more details on prospective system concepts, and to determine development status of systems that might be available for a public demonstration. A total of 36 potential AMWS suppliers were canvassed as part of the survey. These prospective suppliers were identified on the basis of known work on AMWS development, appearance in the literature, or as being known manufacturers of escalators and moving walks. Some suppliers have shown interest in the AMWS program but have not shown sufficient development progress nor interest in the program to warrant inclusion in the final demonstration project report.

The survey resulted in the identification of five potential AMWS developers at, or near, the hardware prototype stage of development. These include, in the approximate order of their development: (1) Dunlop Speedaway, (2) RATP TRAX, (3) Applied Physics Laboratory (APL), (4) Boeing Corporation, and, (5) Dean Research Corporation.

2.0 DESCRIPTIONS OF CANDIDATE SYSTEMS

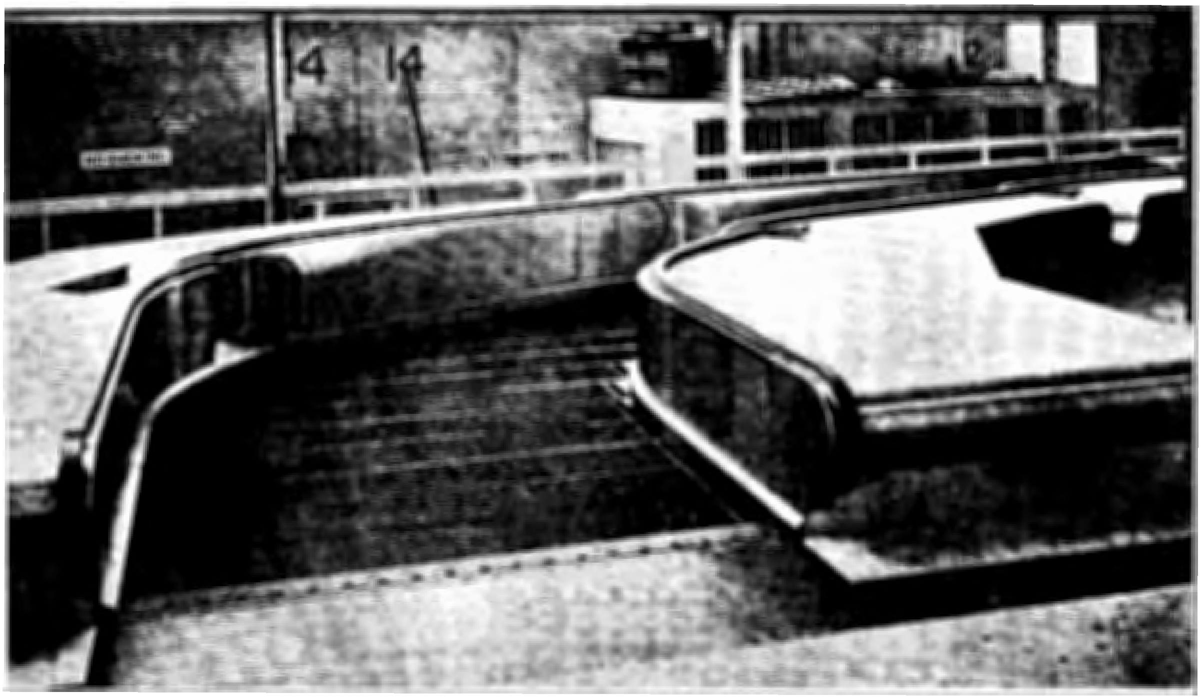
There have been a great many proposals for variable speed moving way transportation systems, but only five developers have been currently identified as being sufficiently advanced in system development to be considered as prospective candidate suppliers of an operational unit for the subject public demonstration program. The basic principles of operation and equipment details of these systems are described and illustrated in this section of the report based on information supplied by the five developers. A following report section deals with a comparative evaluation of the various factors that would affect the possible selection of a system for a public demonstration. Safety and Human Factors considerations for the various systems, as noted previously, are developed in more detail in Report C of the series.

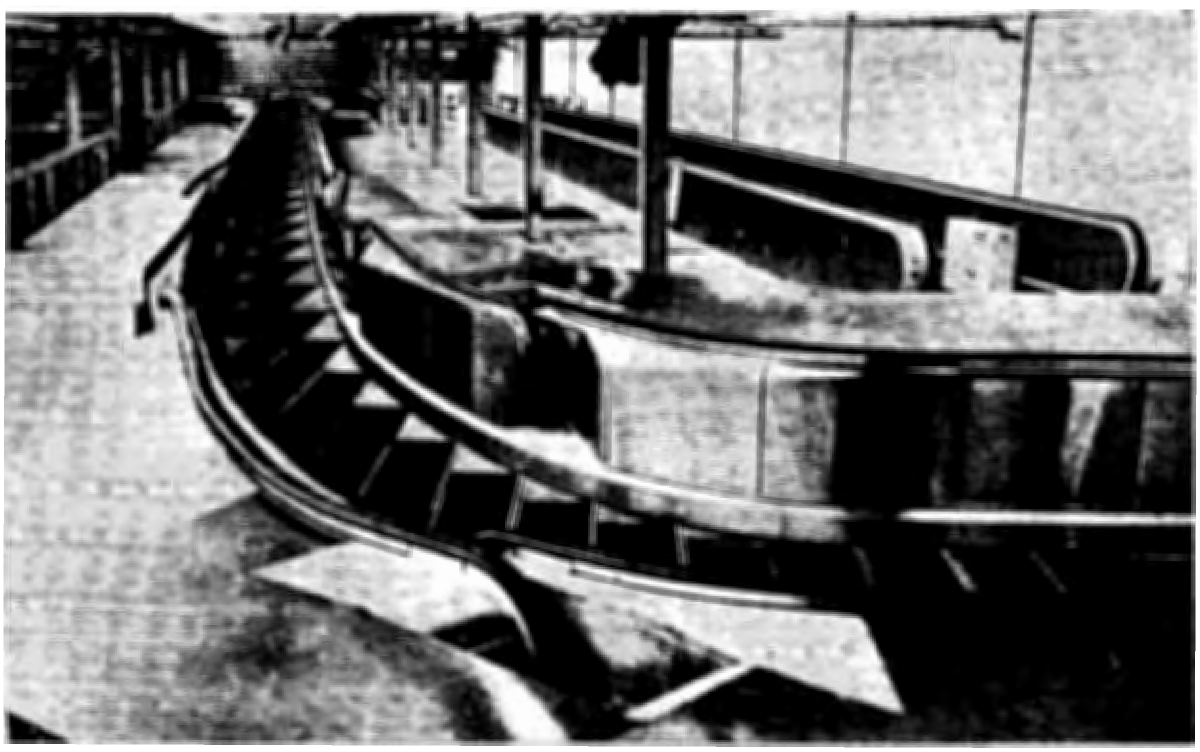
2.1 The Dunlop Speedaway System

The Dunlop Speedaway is the most advanced variable speed accelerating moving walkway system in terms of development, with a background of more than ten years of design, prototype manufacture, and evaluation, equipment component refinement, and user tests. Dunlop currently has available a full scale pre-production model of its system and could fabricate a production system for demonstration on order within a period of about 18 months. Dunlop is a well established manufacturer of escalators and moving walks in Britain, with licensees in other European countries. Its French affiliate is responsible for the extensive installation of the conventional Dunlop Starglide passenger conveyors at the new Charles de Gaulle Airport.

The Speedaway variable speed moving walkway is a one-directional (and reversible) system employing a treadway comprised of wide trapezoidally shaped aluminum extruded pallets linked to each other and supported by rollers running on a tracked guideway. (See Figures 2.1-2.4). Unlike other systems where the treadway surface expands and contracts to provide acceleration and deceleration, the Dunlop treadway surface area remains relatively constant, with the pallets gradually shifting in both a forward and lateral direction to produce variations in speed. The entrance of the Speedaway resembles an escalator or conventional pallet type moving walkway with the exception that it is much wider. The width of the Speedaway pallets and entrance is determined by the system speed ratio. Overall pallet width across the extremities of the 1:5 speed ratio system is 22'-7" (6.9 m) and the clear entrance width

DUNLOP SPEEDAWAY





GENERAL VIEW DUNLOP SPEEDAWAY FULL SCALE FACTORY INSTALLATION. TREADWAY SURFACE COMPRISED OF GROOVED PALLETS SLIDING TRANSVERSE TO EACH TO PROVIDE ACCELERATION, DECELERATION. TOP CURVED ENTRANCE SECTION, BOTTOM, CONSTANT SPEED SECTION IN STRAIGHTAWAY. NOTE MULTIPLE HANDRAILS. EACH OF THESE HANDRAILS OPERATES AT A CONSTANT SPEED, 4 HANDRAIL TRANSITIONS FROM ENTRY TO CONSTANT SPEED.

FIGURE 2.1

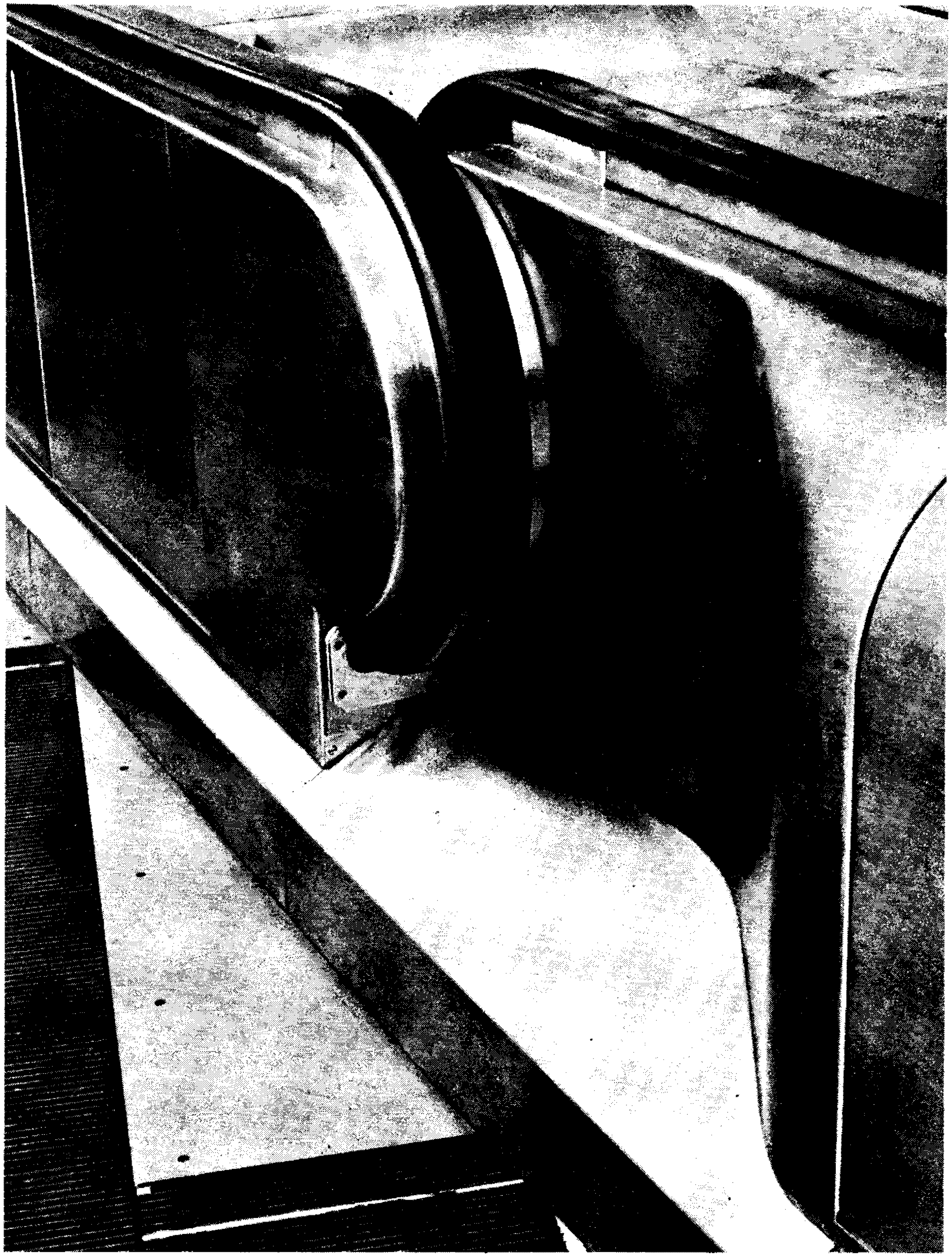
or portal is 9'-9" (3.0 m). The forward and lateral trajectory of the pallets producing the Speedaways' variations in speed results in curved acceleration and deceleration zones and an "S" shaped alignment configuration.

The Speedaway handrail system is comprised of a sequence of conventional constant speed handrails of the familiar escalator type running in series. The handrail design for the 1:5 ratio system consists of seven separate constant speed handrails, with the handrail speed for each segment set at the average speed of the walkway section within that segment. Dunlop has designed the handrail sequence so that there is a minimum displacement of hand position relative to body position during passenger movement along the acceleration and deceleration sections. The high speed section handrail runs at the same speed as the treadway. Balustrade detailing in handrail transition sections have also been designed to facilitate hand transfer between handrails, as well as to avoid possible passenger entrapment or catching of hand carried articles. (See Figure 2.3.)

A simple, rubber tired friction driving mechanism powered by an electric motor is utilized to propel the continuous loop of linked pallets forming the treadway over the constant speed section. Handrails are driven by chain linkages and pulleys somewhat similar to the arrangement of the conventional escalator described in report Section 1.3. Comb-plating for the Speedaway resembles that of conventional escalators and pallet type moving walks. Speedaway requires a level, or nearly level installation site.

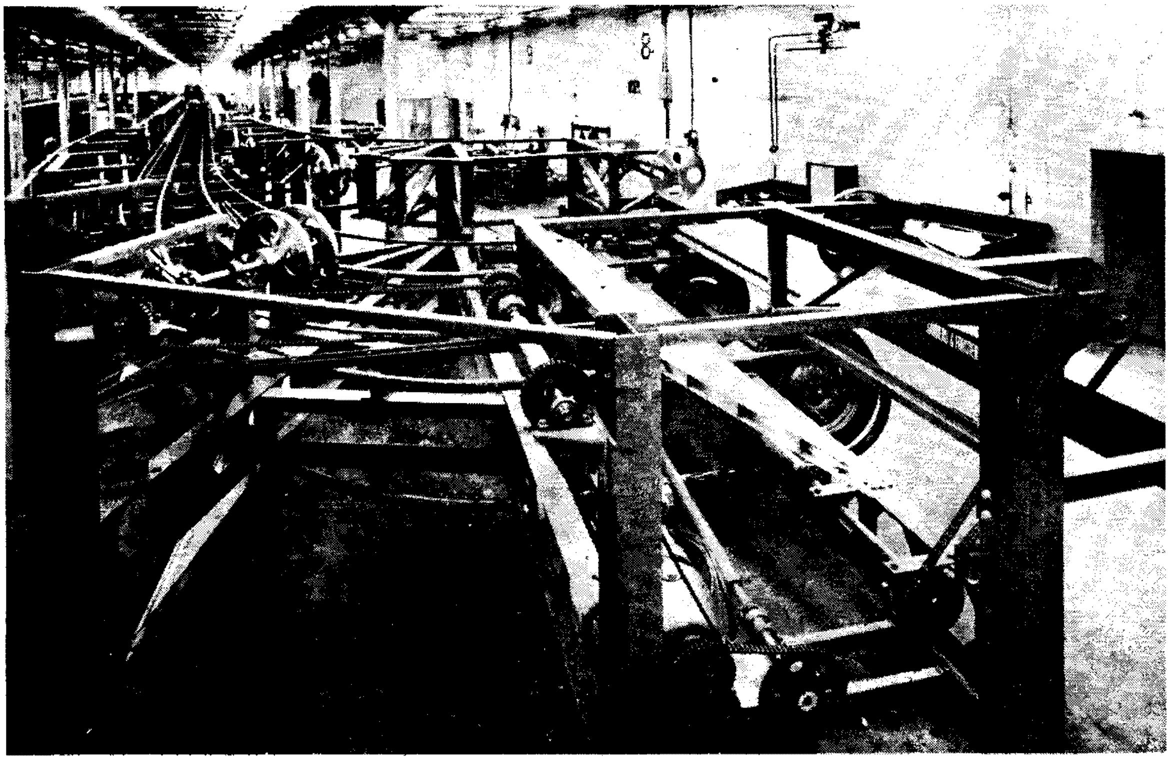
VIEW OF SPEEDAWAY EXIT ILLUSTRATING GROOVED PALLETS AND STATIONARY COMBPLATE.

FIGURE 2.2

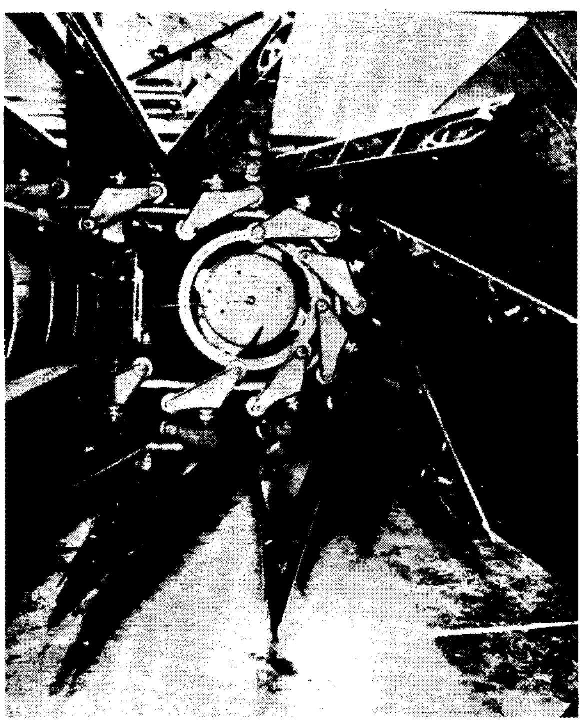


CLOSE UP OF HANDRAIL AND BALUSTRADE TRANSITION SECTION AND TREADWAY. TRIANGULAR, NON-GROOVED TREADWAY SURFACES EMERGE FROM BENEATH BALUSTRADES IN ACCELERATION ZONE, RETREAT BENEATH BALUSTRADE IN DECELERATION ZONE.

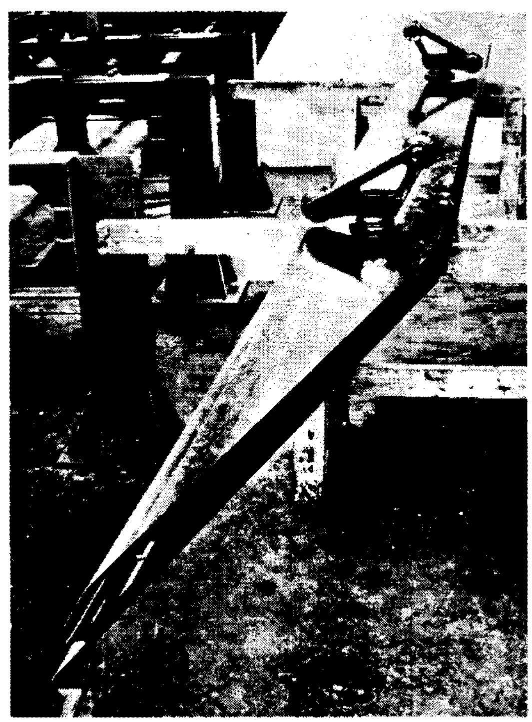
FIGURE 2.3



SPEEDAWAY SUPPORT FRAME AND DRIVE MECHANISM.



RUBBER TIRE DRIVE MECHANISM AND TREADWAY PALLET RETURN.



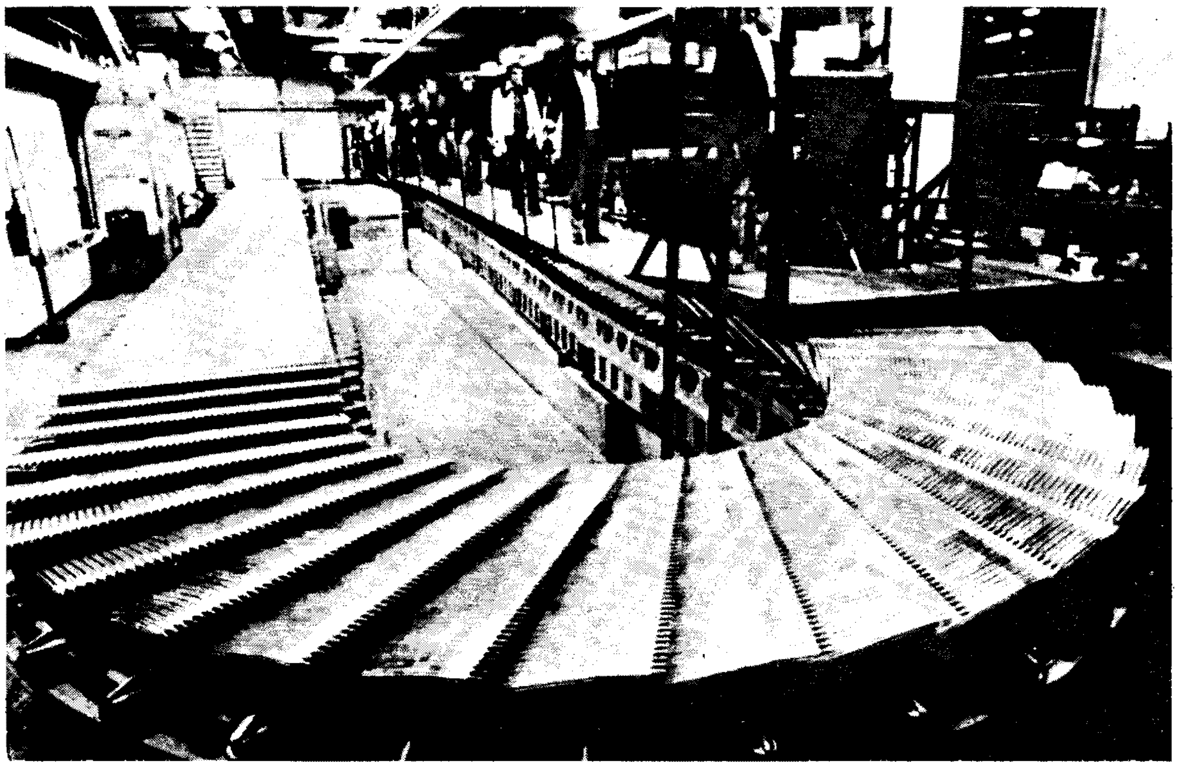
TREADWAY PALLET AND BOGIES.

FIGURE 2.4

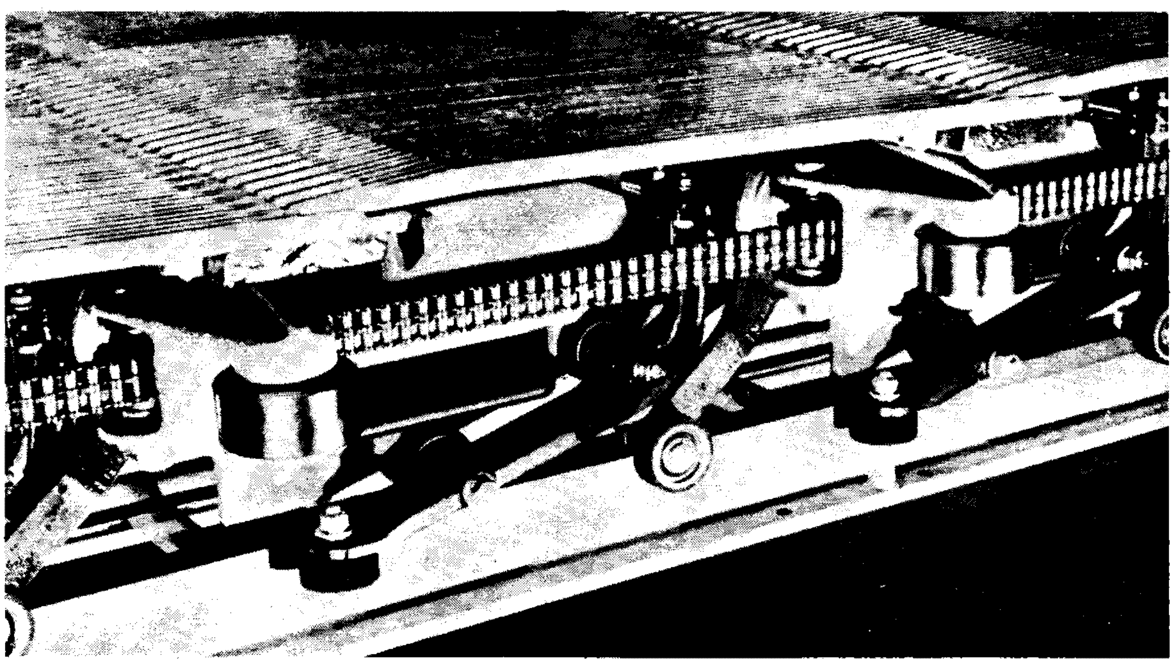
2.2 RATP TRAX System

The TRAX system, under development by the Regio Autonome de Transports Parisiens (RATP - Paris Transit Authority), is a full scale variable speed walkway prototype developed to the point where a public demonstration is programmed in Paris for early 1979. The Authority is not a manufacturer like Dunlop, and therefore would require a licensee to fabricate, install and support a production model of the system for a United States demonstration. The treadway and a partially operational handrail for the TRAX system has undergone user tests. (See Figures 2.5 thru 2.8.)

The TRAX variable speed passenger conveyor is a two directional loop system with a continuous treadway comprised of grooved, intermeshing and overlapping pallets, sliding over and combing each other, and combed by means of conventional combplates at the entry and exit to the system. The longitudinal sliding movement of the pallets required to produce the expansion and contraction of the treadway surface necessary for acceleration and deceleration is controlled by a continuous closed loop quadrangular chain linkage on the underside of each pallet. The movement of the connecting chain and plates is in turn controlled by sprockets and a telescoping tube assembly running in variable gauge tracks flanking the underside of the treadway. The spacing or gauge of the running track determines the configuration of the undercarriage assembly of sprockets, telescoping tubes and connecting chain linkages, the movement of the treadway pallets. The tracks are spread wider and overlapping pallets meshed closer together in the slow speed section of the conveyor and conversely, the tracks are closer together and

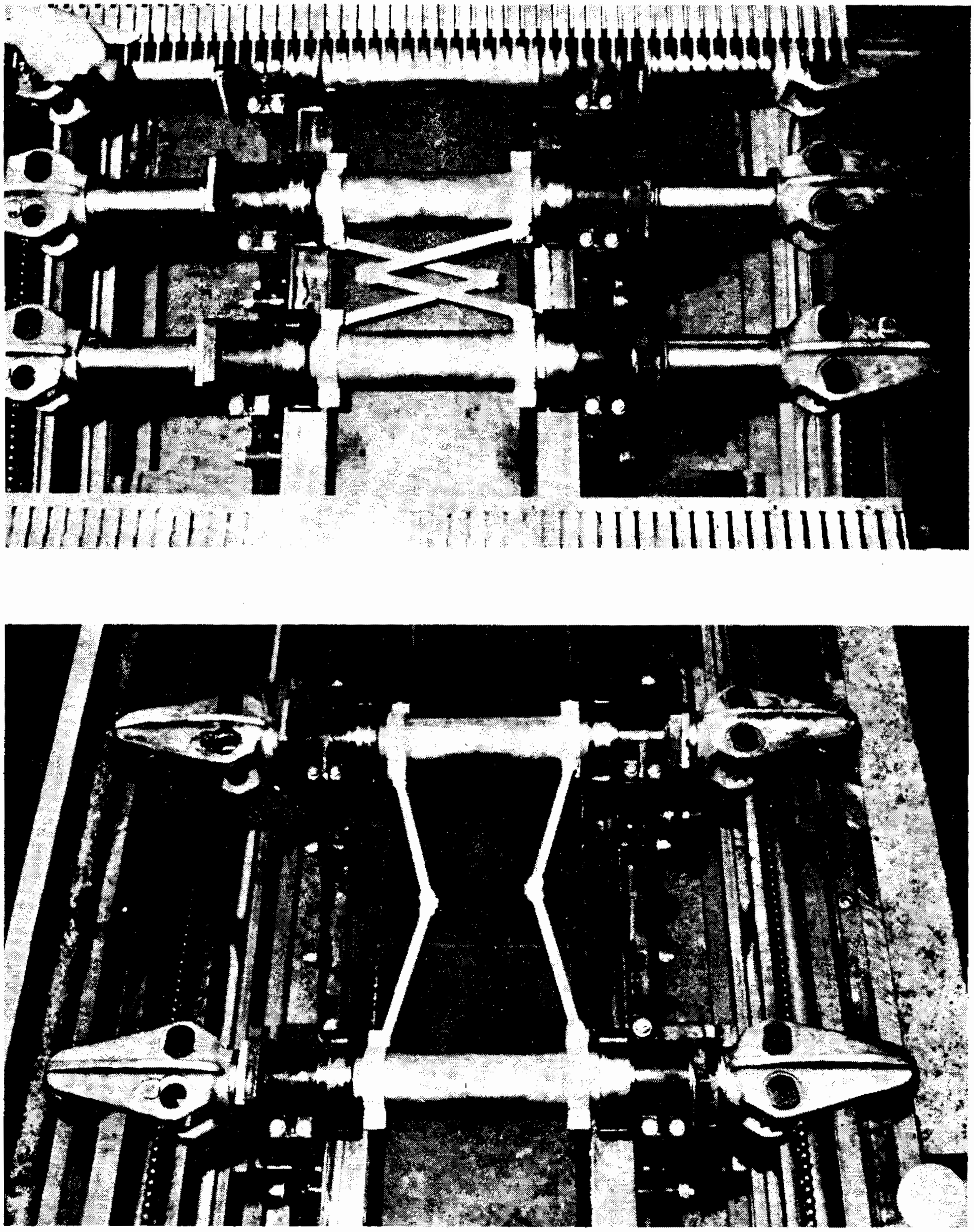


GENERAL VIEW OF TRAX PROTOTYPE LOOP. TREADWAY SURFACE FORMED OF GROOVED SLIDING PLATES, COMBING EACH OTHER AND COMBED BY STATIONARY COMB PLATES AT ENTRY AND EXITS.



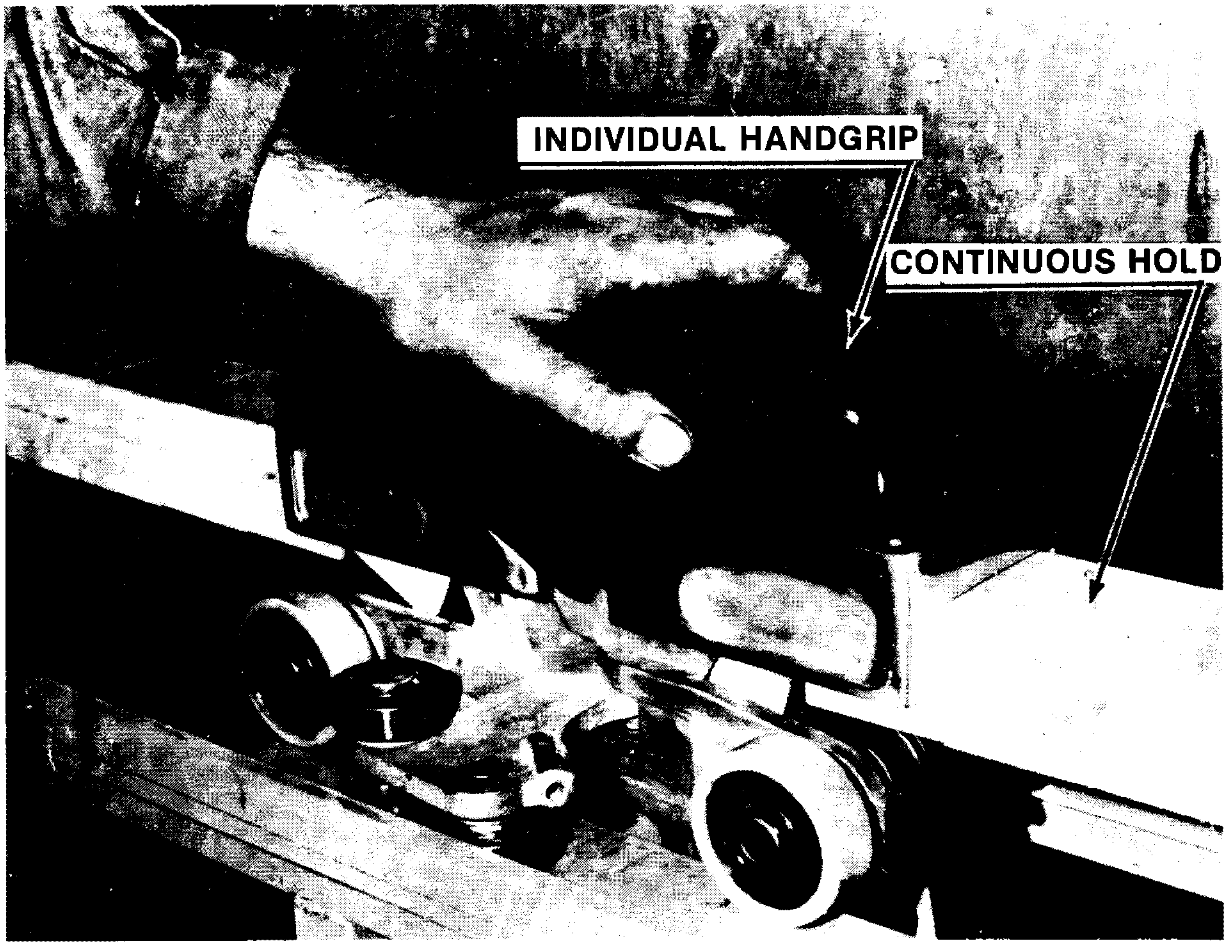
SIDE VIEW TREADWAY SURFACE, EXPANDED HIGH SPEED CONFIGURATION, GUIDEWAY TRACK, ROLLERS, AND PLATE CONTROL CHAIN.

FIGURE 2.5



A CONSTANT LENGTH CHAIN, CONTROLLED BY ROLLERS, AND A VARIABLE GAUGE TRACKED GUIDEWAY PROVIDES THE SPEED VARIATION IN THE TRAX SYSTEM. THE GUIDEWAY DETERMINES THE CHAIN CONFIGURATION SHIFTING TREADWAY SECTIONS TO ELONGATE AND CONTRACT THE WALKWAY. TOP: SLOW SPEED CONFIGURATION. BOTTOM: HIGH SPEED CONFIGURATION.

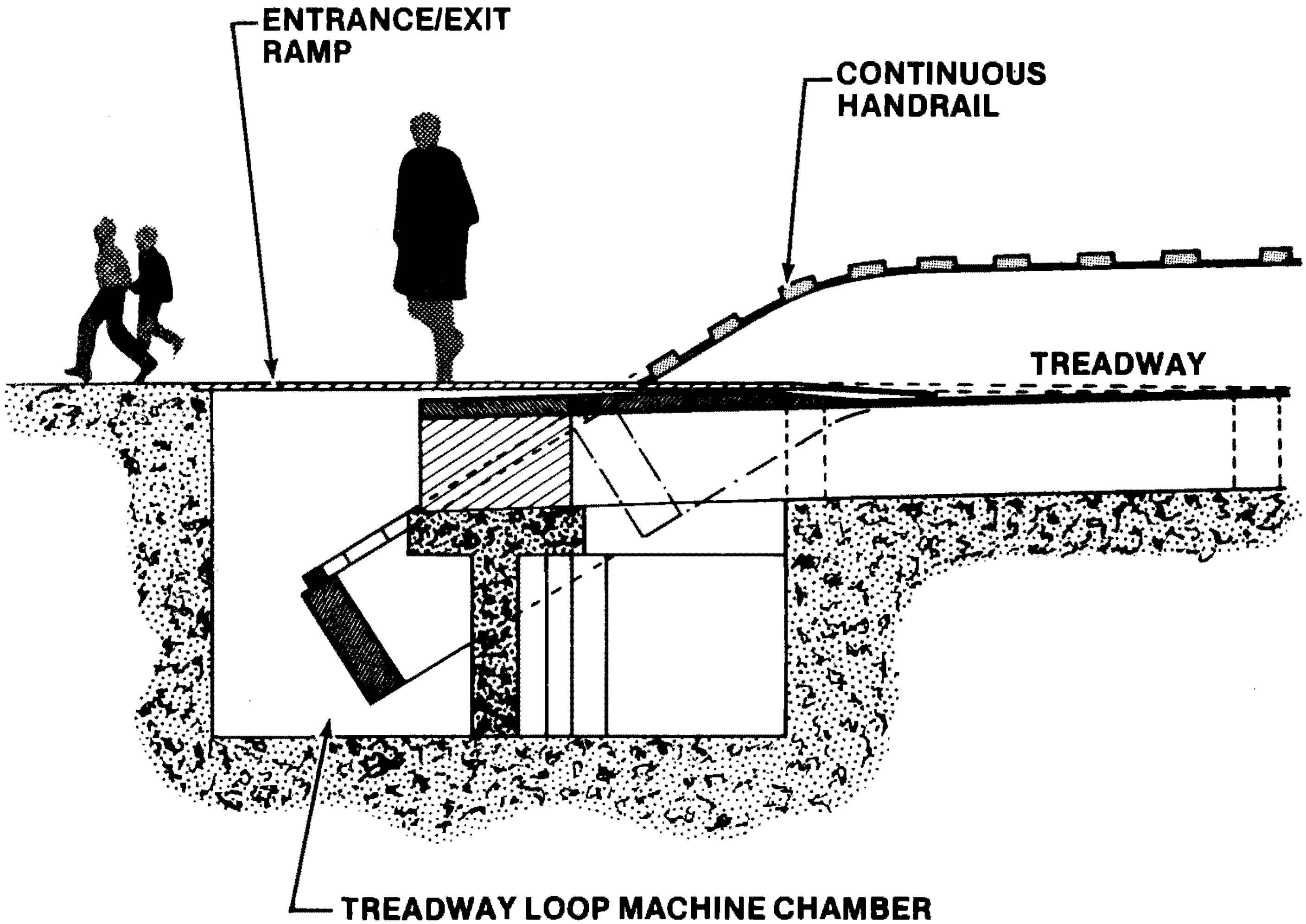
FIGURE 2.6



The Trax Handrail is comprised of individual handgrips superimposed upon a continuous articulated hand hold.

FIGURE 2.7

TRAX SYSTEM



CROSS SECTION TRAX HANDRAIL RETURN CONFIGURATION.

FIGURE 2.8

overlapping pallets spread longitudinally further apart in the high speed section.

The TRAX handrail design consists of a solid individual handgrip and a continuous articulated section handhold linked to the driving mechanism, so that the handgrip operates at the same speed as the walkway. (See Figure 2.7). The articulated section handhold, actually the cover over the handrail driving chain, could be grasped for support if necessary, though providing a less comfortable grip. Use of individual handgrips would help in spacing the passengers to limit bunching which has been identified as a potential problem on linear variable speed walkway systems such as TRAX (see Report C for details). Because of the loop configuration of the TRAX system, as well as its unique handrail design, the handrail return would be different than that of conventional moving walk systems and the Speedaway. As shown in Figure 2.8, the handrail would follow an angular path into the treadway loop machine chamber at the ends of the system. Balustrade detailing in other sections of the walk would be similar to conventional system designs. Combplating would also be similar to conventional designs. The main drive mechanism and various chain drive linkages for the pallets and handrails is somewhat similar to that previously described for the conventional escalator.

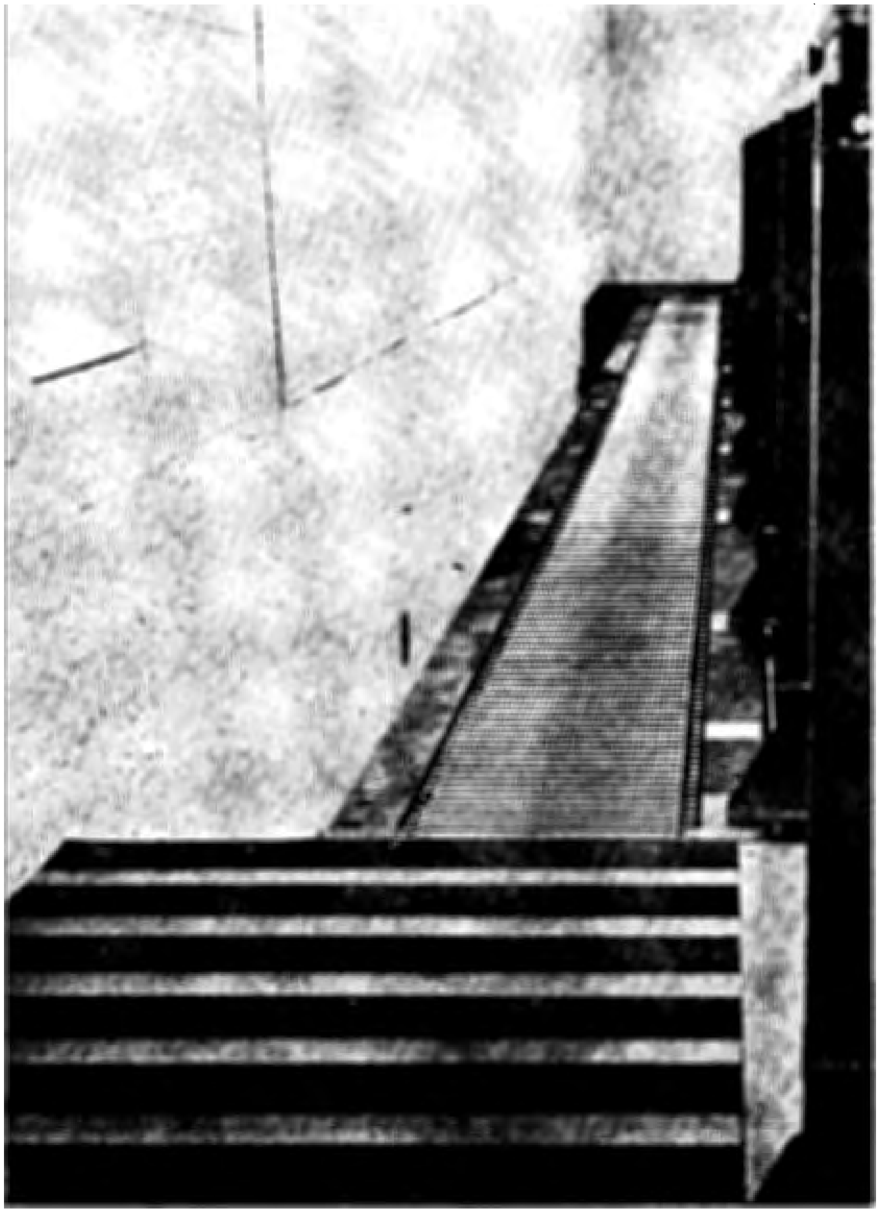
Reportedly, the TRAX system can be adapted to vertical curve radii of 25 m, and horizontal curve radii of 50 m, as well as grades of up to 15%. (Note: Grades would be subject to code restrictions related to speed.) The added vertical and horizontal alignment flexibility of the system would help increase its potential number of applications.

2.3 Applied Physics Laboratory (APL) System

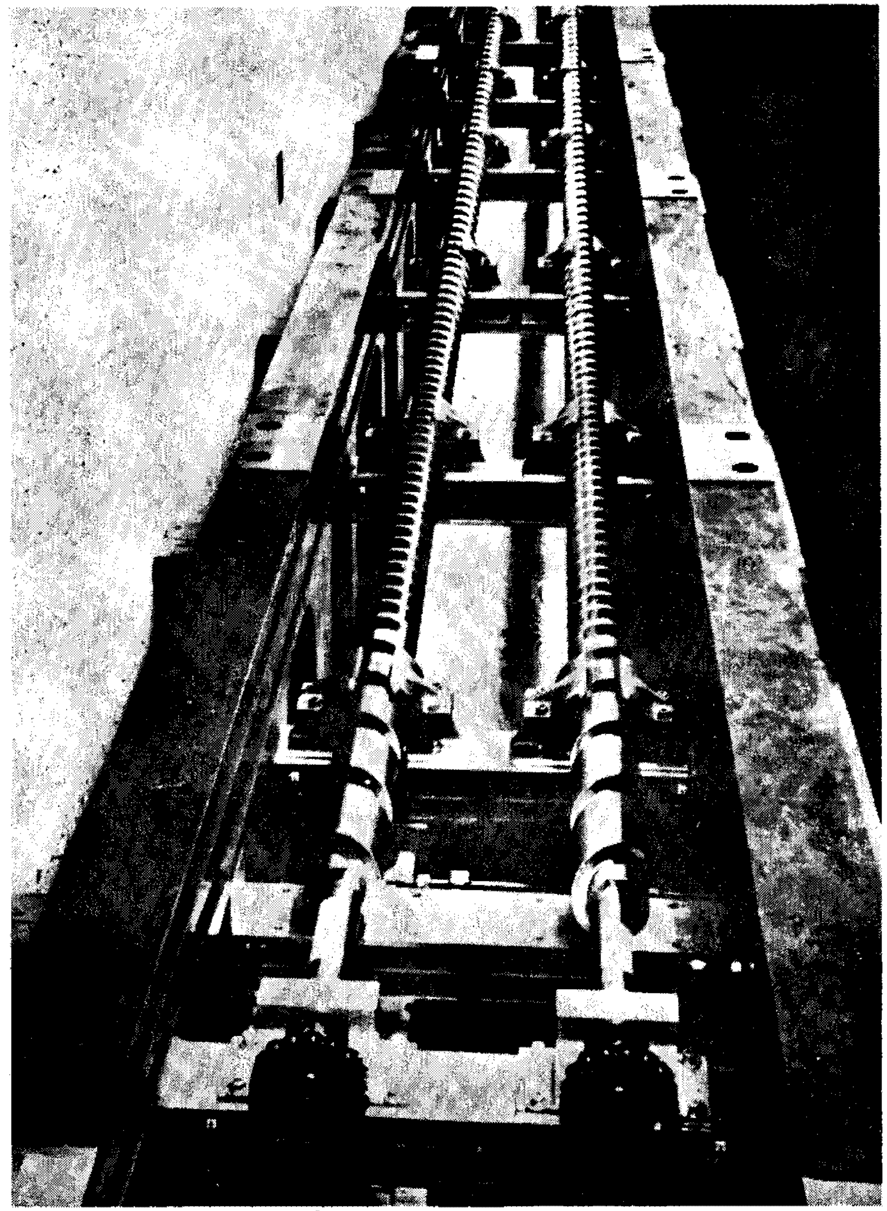
The Johns Hopkins University (APL) variable speed walkway exists as a 31 ft. long (9.5 m), 18 inch wide (457 m), laboratory prototype which has undergone several years of operational and user testing. The University is, of course, not a potential manufacturer of the system, and would require a licensee or other type of contract arrangement to produce a full scale production model and support a demonstration. There has been limited development progress on the system since it was first built and tested because of the lack of funds. The prototype, which is a 1:3 speed ratio unit, has been in use with a stationary handrail. A variable speed handrail concept has been designed, but not fabricated or demonstrated.

The APL variable speed passenger conveyor is a linear one-directional (and reversible) design using a treadway comprised of overlapping and intermeshing leaves, combing each other, and combed at the system entrance and exit. (See Figures 2.9-2.12.) The leaves are linked together to form an endless chain and are supported by a variable gauge track. The elongation and contraction of the walkway surface necessary to provide acceleration and deceleration of the system is accomplished by variable pitch screws beneath the treadway which change the treadway leaf angle. In the contracted or slow speed configuration, the interconnecting leaves are deployed in an elevated position, whereas in the expanded high speed configuration, they move into a position nearer to the horizontal. Each of the individual connecting leaves forming the treadway is curved in such a way that the composite surface remains practically level during changes in the leaf angle.

FIGURE 2.9



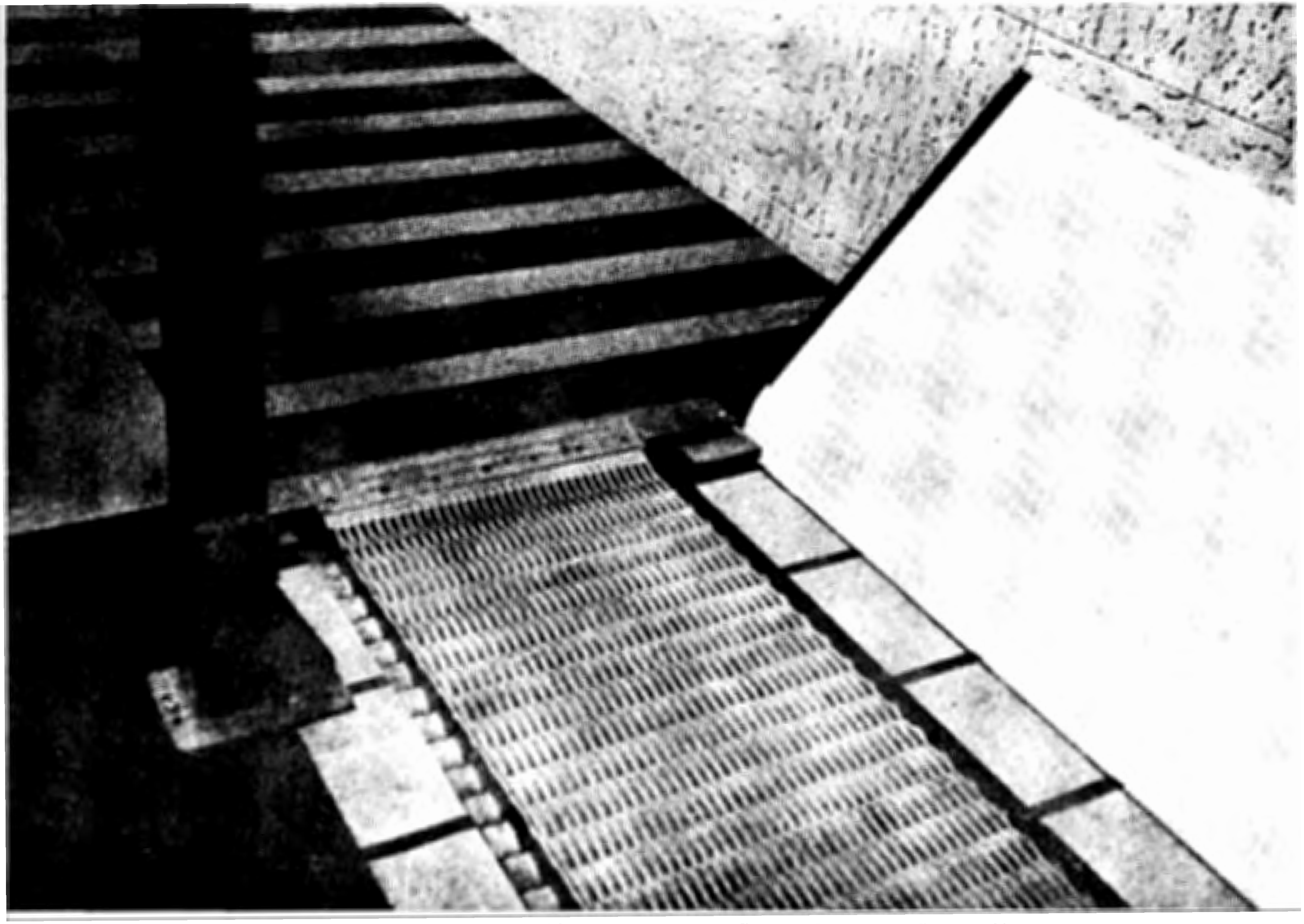
TREADWAY SURFACE IS FORMED OF INTERMESHING LEAVES COMBING EACH OTHER AND COMBED AT ENTRY AND EXIT.



VARIABLE PITCH SCREW DRIVING UNIT CONTROLS TREADWAY LEAF ANGLE AND THE ELONGATION AND CONTRACTION OF THE TREADWAY SURFACE.

APL

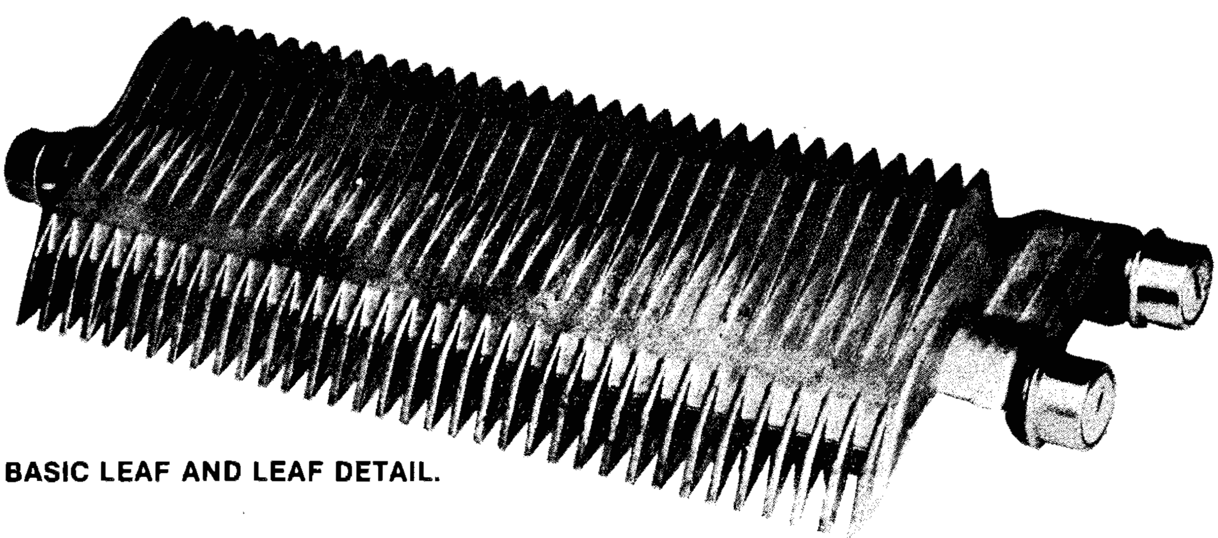
FIGURE 2.10



VIEW SHOWING STATIONARY COMBPLATE AT END OF PROTOTYPE UNIT.

APL

TREADWAY SURFACE. (a) STEP ON SPEED (b) ACCELERATION SECTION (c) CONSTANT HIGH SPEED SECTION.

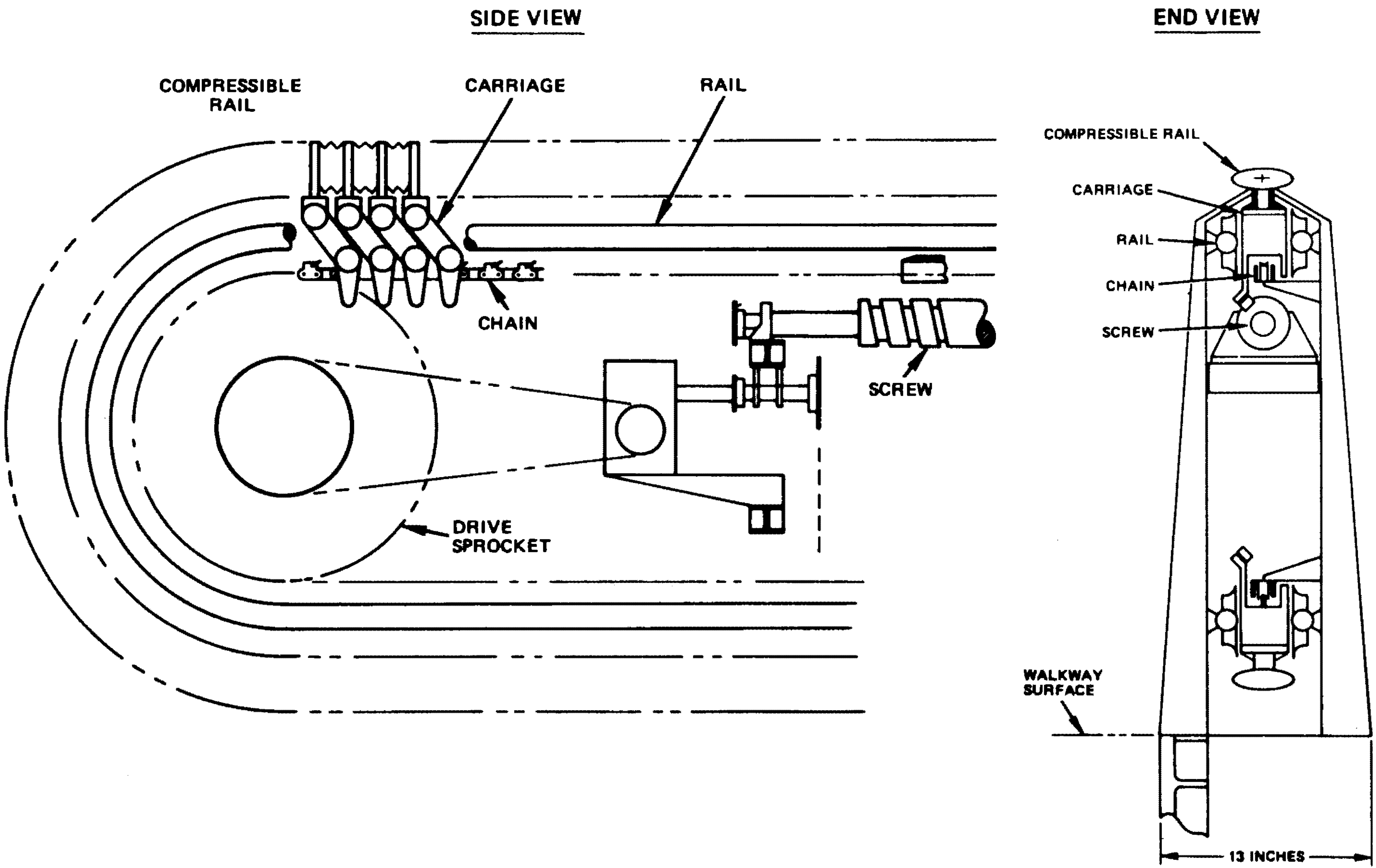


BASIC LEAF AND LEAF DETAIL.

FIGURE 2.11

FIGURE 2.12

ACCELERATING HANDRAIL CONCEPT



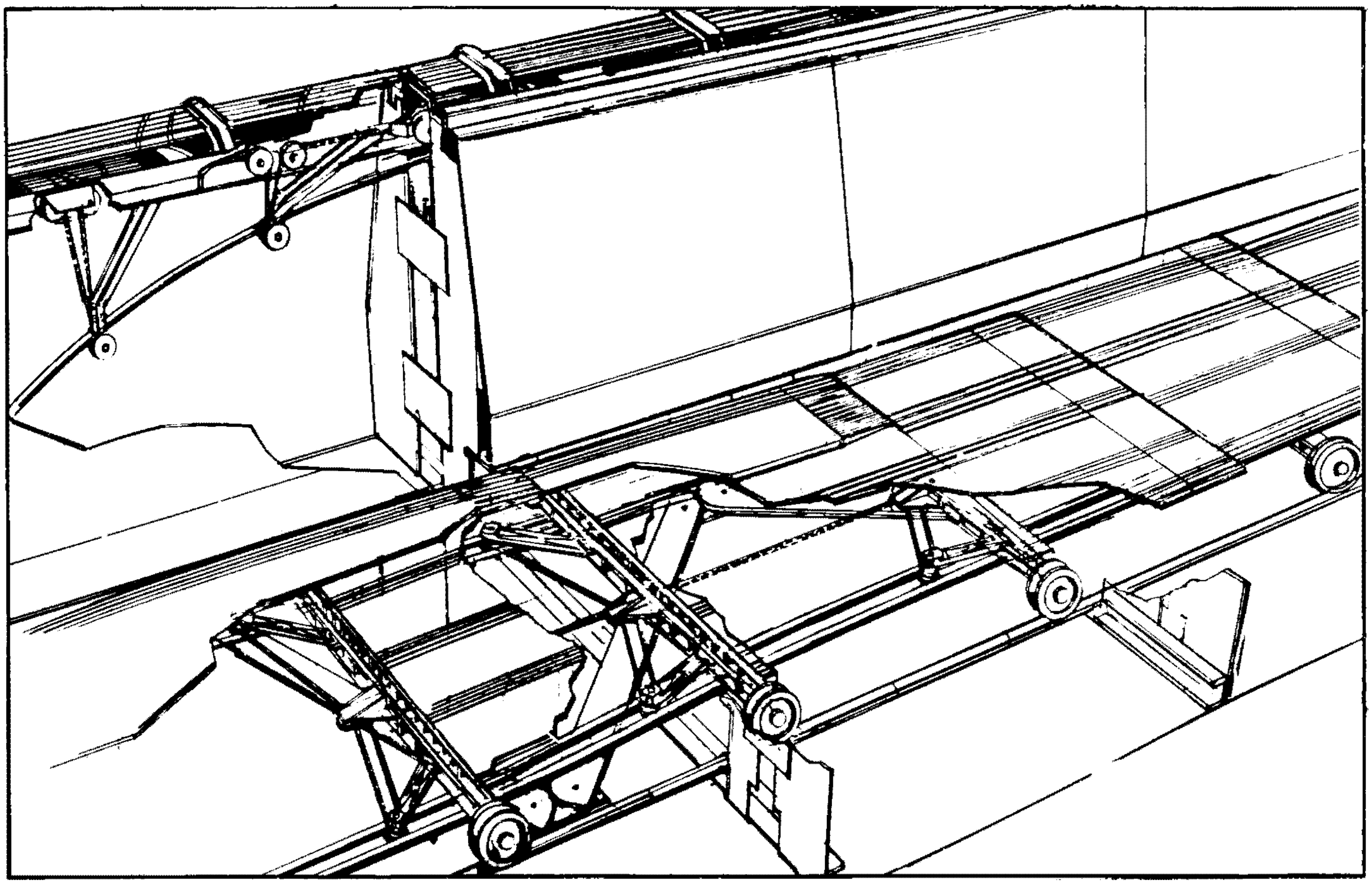
Balustrade and combplate detailing for a full scale system would be similar to that of conventional moving walks. The APL handrail concept is based on the use of a compressible accordion type handrail which would synchronously expand and contract with the treadway surface. The variable pitch screw driving mechanism in acceleration and deceleration sections would be supplemented by a chain drive in the central constant speed section in longer installations. As with all linear systems, the APL system is subject to pedestrian bunching and appropriate measures would be required to limit this problem.

The APL system has the advantage of dimensional compatability with existing one-directional conventional moving walkways and, therefore, could be used for retrofitting. The system could also be built in varying widths and be adapted to limited vertical curves and to the maximum grades allowed by the revised code.

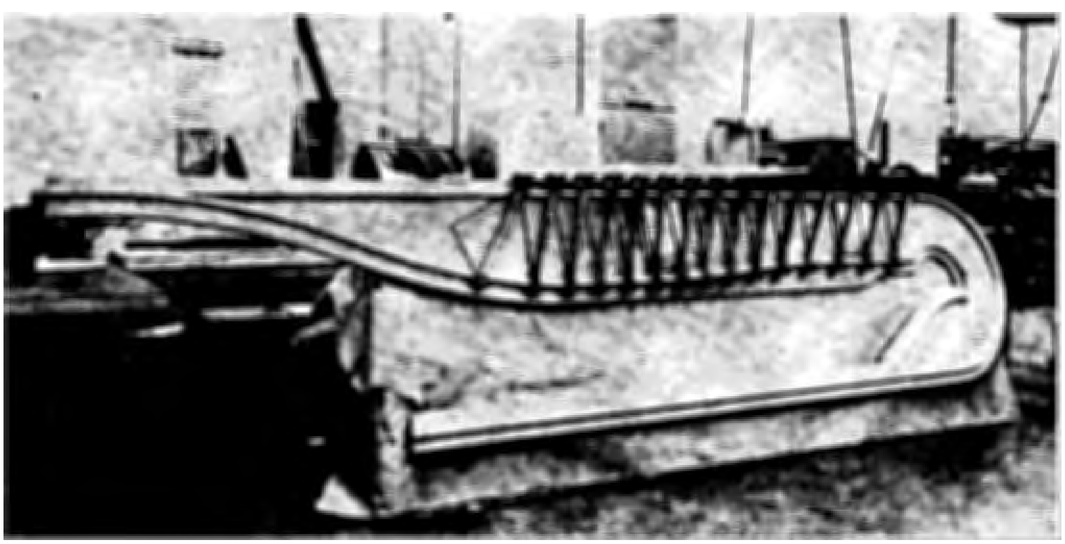
2.4 The Boeing System

Boeing Company is developing a variable speed pedestrian conveyor with prototype completion scheduled for late 1978. While the system development had not advanced to the same degree as the others discussed in preceding sections, considerable confidence exists in the ability of the Boeing Company as a manufacturer of transportation equipment to produce a demonstration unit and to provide the necessary logistic support for a demonstration.

The Boeing system resembles TRAX in many respects. Like TRAX, it is a linear system configured in a two directional loop, and utilizes a treadway of grooved overlapping and intermeshing sliding pallets. (See rendering, Figure 2.13.) The sliding pallets would be mounted on rollers running in flanking tracks. Propulsion would be supplied by a linear induction motor. Variable speed performance would be achieved by cam tracks and linkage mechanisms to provide the changing overlay of the intermeshing pallets. The spread of the pallets and length of the treadway would be increased in the acceleration section and decreased in the deceleration section. A matching speed handrail is proposed employing overlapping sections to form a telescoping variable speed handrail for the acceleration/deceleration areas. Site adaptability of the Boeing system would be favorable because its relatively shallow depth would permit practical on grade installation.



RENDERING OF TELESCOPING HANDRAIL AND TREADWAY. TREADWAY COMPRISED OF GROOVED SLIDING PLATES ARTICULATED BY UNDERCARRIAGE RUNNING ON TRACKS. LINEAR INDUCTION MOTOR DRIVE.



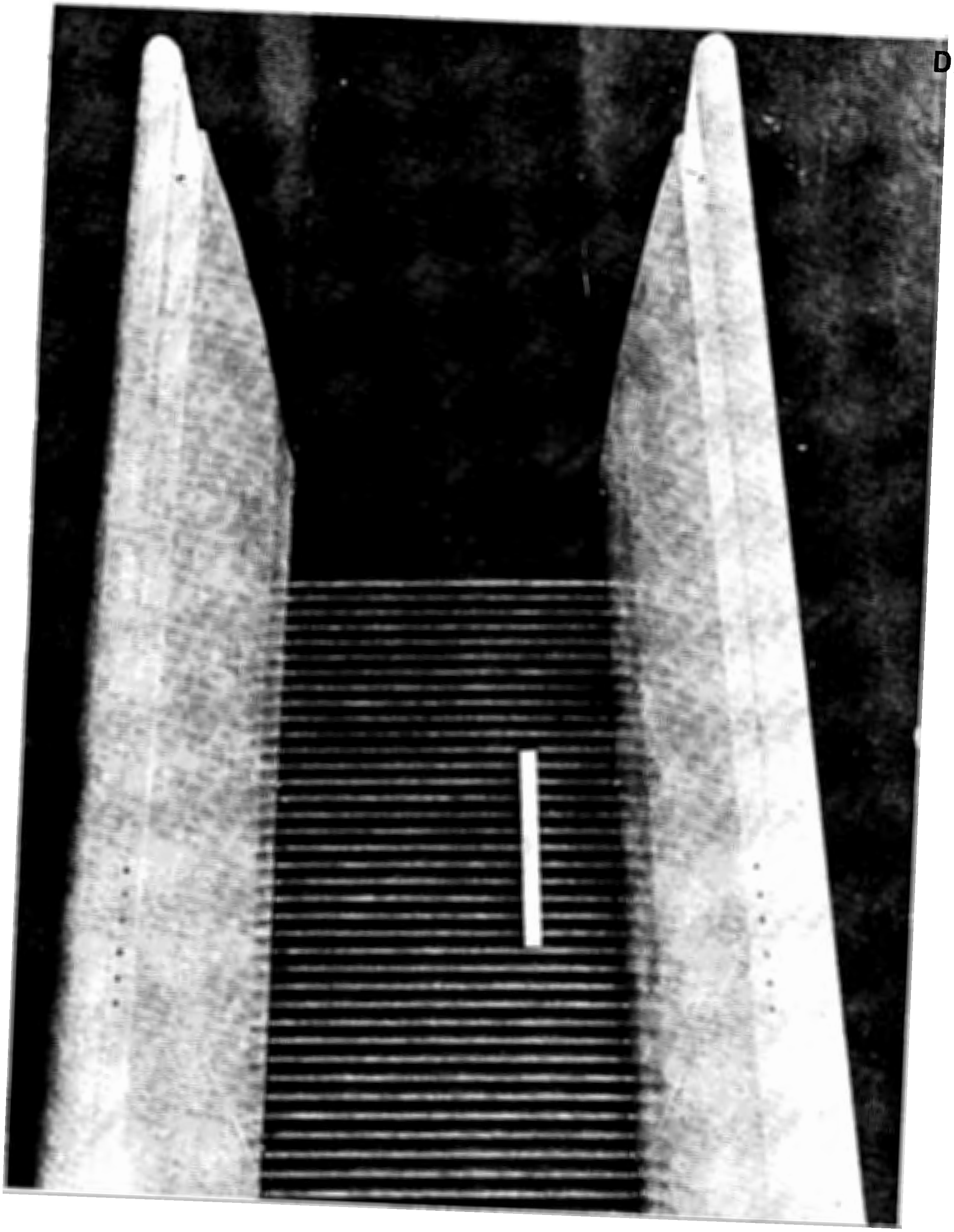
MOCKUP OF TELESCOPING HANDRAIL, BOEING SYSTEM.

FIGURE 2.13

2.5 Dean Research Corporation System

The Dean Research Corporation, a manufacturer of specialized industrial conveyor systems has built a short prototype for a linear one directional (and reversible) variable speed walkway based on the use of a series of abutting steel rollers. The prototype has undergone limited tests with passengers of varying ages, types of footwear, and physical handicaps, reportedly with encouraging results. Because of the modular simplicity of a roller treadway concept, it potentially could be fabricated in a relatively short time. Such a system would be highly site adaptive because of its shallow depth and could be designed for horizontal and vertical curve alignments as well as for limited grades. (Figure 2.14)

The basic principle of the system is the programming of individual rollers for different speeds to produce gradual acceleration or deceleration. The propulsion system would consist of a series of motors with drive connections to the rollers. An operational handrail has not yet been developed, but a solid roller driven handgrip, running at a speed synchronous with the treadway speed has been proposed by the developer. Insufficient design details or user acceptance data is available to adequately evaluate this system at this time. Individual powered rollers could limit possible consequences of entrapments. Additionally, since there would be no contraction of the treadway surface as with other linear systems, bunching effects should be minimized.



THE DEAN RESEARCH CORPORATION PROTOTYPE IS A LINEAR SYSTEM CONSISTING OF A SEQUENCE OF ABUTTING 1" (25.4mm) DIAMETER VARIABLE SPEED STEEL ROLLERS.

FIGURE 2.14

3.0 SUMMARIES OF SYSTEM CHARACTERISTICS

The use and acceptance of accelerating variable speed moving walkway systems will not only be based on the identification of potential useful applications and existence of sufficient user demand, but consideration of other factors as well. Among the factors that will require consideration are:

- Site Adaptability - relating to the configuration, dimensions, alignment flexibility, structural requirements and the basic physical envelope of the system;
- Performance Characteristics - system speeds, acceleration, deceleration, capacity, safety features;
- Costs - manufacturing, furnishing and installation, site- preparation, operations and maintenance, insurance;
- Developers Qualifications - experience, production capabilities, installation capabilities, financial resources, support capabilities for maintenance, repair, replacement parts, (etc);
- User Acceptance - system appearance, safety and human factors design, installation environment, noise, vibration, heating, ventilation, air conditioning, lighting, weather protection.

The various system aspects listed above are developed in the following sections: 3.1 Siting Characteristics, 3.2 Passenger Service Characteristics, 3.3 Costs, 3.4 Developer Qualifications, and 3.5 Safety and Human Factors, (more detail on this subject provided in Project Report C).

3.1 Siting Characteristics

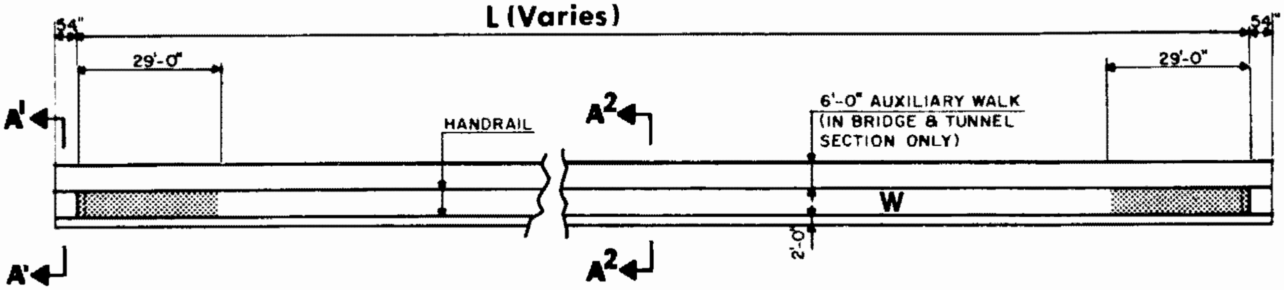
The system configuration, its overall dimensions, structural requirements, its relative adaptability to on-site grade changes or shifts in alignment are significant determinants of the number of locations where an AMWS could be applied. The generalized plans and sections of the five systems discussed in preceding sections of the report are shown on Figures 3.1 and 3.2 following. Additional data is summarized on Table 3.1.

Naturally, systems with smaller dimensional envelopes are simpler to site. The APL and Dean Research linear one-directional systems have the smallest cross sections, and are adaptable to limited changes in horizontal and vertical alignments, which make these systems potentially useable in more locations, particularly where a one directional movement situtation might be encountered. Both of these systems are suitable for retrofitting or replacement of existing in-line conventional walkway systems. The Dean system as presently conceived is amenable to surface mounting.

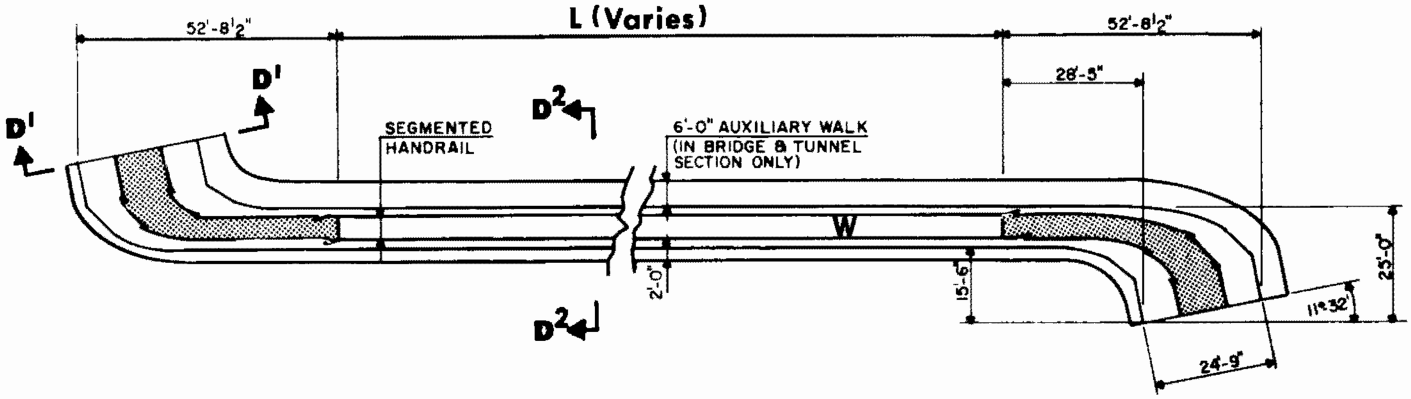
The Dunlop Speedaway has several dimensional restraints limiting its wider application. However, in new construction these dimensional restraints would be less of a factor. The system's "S" configuration (either normal or reverse "S"), inherent in the lateral acceleration concept, is a constraint where the direction of pedestrian flow is in a straight line, or in existing structures with a rectangular grid column spacing. The greater depth of the Speedaway due to its pallet return chamber is a structural design and clearance factor in elevated sections or where there are floor spaces in use beneath the system. The flaring

PLAN VIEWS CANDIDATE AMWSS

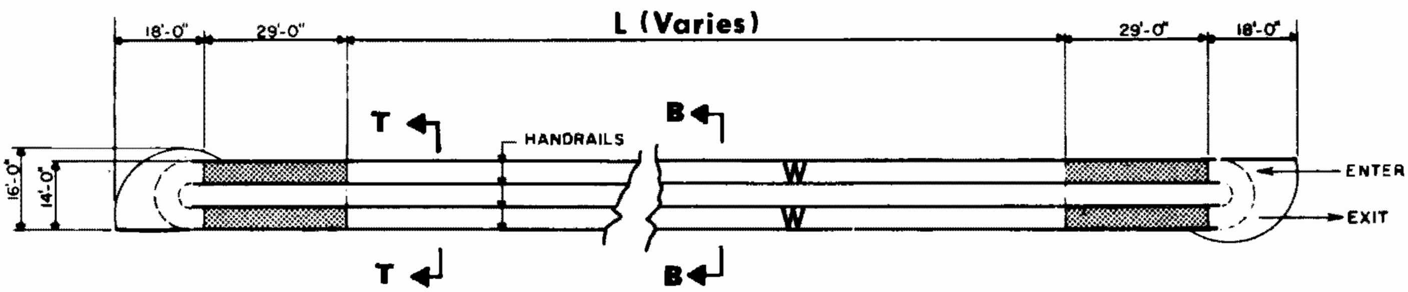
ALL DIMENSIONS APPROXIMATE - SUBJECT TO CHANGE



APPLIED PHYSICS LABORATORY - DEAN RESEARCH SYSTEMS



DUNLOP SPEEDAWAY SYSTEM



W = 40" ±

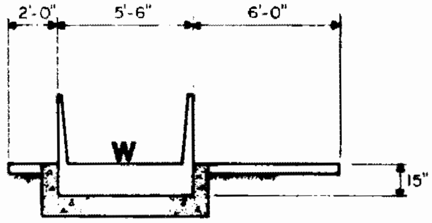
TRAX - BOEING SYSTEMS

ACCELERATION
DECELERATION SECTIONS

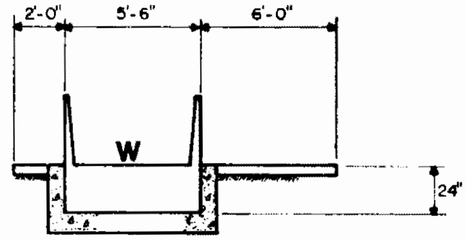
FIGURE 3.1

SECTION VIEWS CANDIDATE AMWSs

ALL DIMENSIONS APPROXIMATE - SUBJECT TO CHANGE



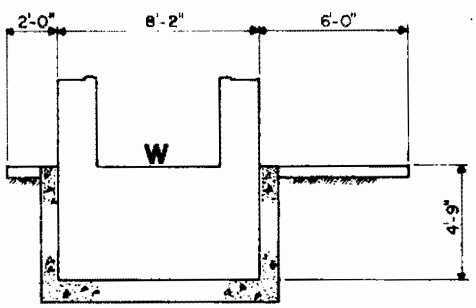
SECTION A²-A²



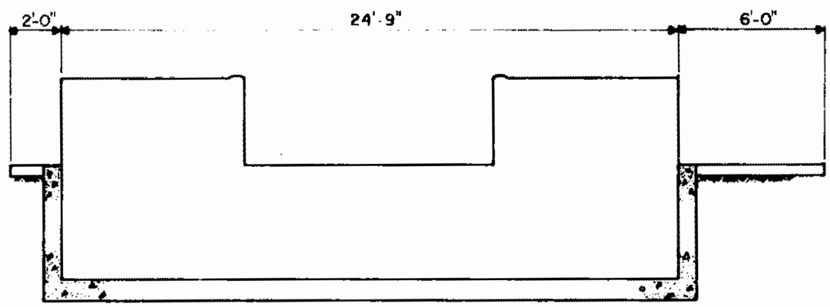
SECTION A¹-A¹

APPLIED PHYSICS LABORATORY - DEAN RESEARCH SYSTEMS

(FLOOR LEVEL MOUNTING THESE SYSTEMS POSSIBLE)

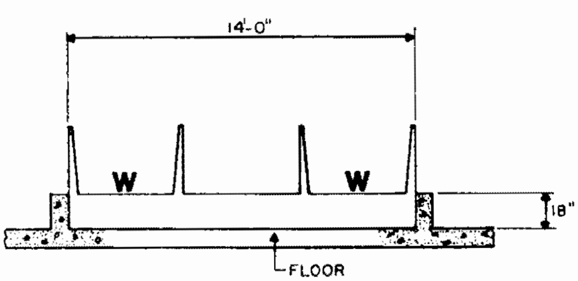


SECTION D²-D²



SECTION D¹-D¹

DUNLOP SPEEDAWAY SYSTEM



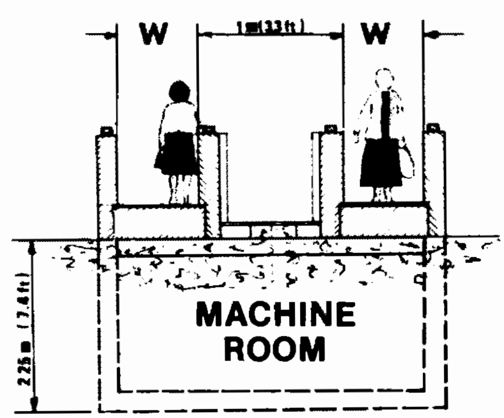
SECTION B-B

BOEING SYSTEM

FLOOR LEVEL MOUNTING POSSIBLE

(TWO-WAY)

W = 40" ±



SECTION T-T

TRAX SYSTEM

(TWO-WAY)

FIGURE 3.2

ACCELERATING MOVING WALKWAY SYSTEMS

SITING CHARACTERISTICS

TABLE 3.1

	ITEM \ MODEL	DUNLOP SPEEDAWAY	RATP TRAX	JOHNS HOPKINS A.P.L.	BOEING	DEAN RESEARCH
1.	Configuration	One direction, reversible.	Two directional Loop	One direction, reversible	Two directional loop.	One direction, reversible.
2.	Width: Entry/Exit	30 ft. including pit areas.	14-16 ft. throughout depending on tread and sidewalk widths.	Similar 40 in. tread escalator, approx. 6 ft. throughout	14-16 ft. throughout depending on tread and sidewalk widths.	Similar 40 in. tread escalator, approx. 6 ft. throughout
	High Speed	8 ft., 2 in.				
3.	Depth Below Grade:					
	Entry/Exit	57 in. (1)	7.4 ft. machine chamber depth	24 in. (1)	N.A.	N.A., but similar to APL.
	High Speed	57 in. (1)	20 in. (1)	15 in. (1) (2)	18 in. (2)	(2)
4.	Maximum Grade	Level site required	± 15% (3)	± 27% (3)	± 12-13% (3)	± 7% (3)
5.	Alignment Adaptability:					
	Horizontal Curve	Straight line.	164 ft. rad min.	Straight line	Straight line.	N.A., but possible with tapered rollers.
	Vertical Curve	Radius 1640 ft.	82 ft. rad.	50 ft. radius, high speed section.	N.A., but possible.	N.A., but possible.
6.	Loading: Dead weight (in lb. units)	Varies, 8.3 K per support pad in curved section, 1.4 K in high speed	800 #/L ft. - accel/decel; 400 #/L ft. - high speed.	Single lane: 90 #/LF.	60 #/SF accel./decel. 50 #/SF high speed	240 #/LF
	Loaded Weight	Live load 45 #/SF	Live load 188 #/L ft.	165 #/LF	N.A.	440 #/LF

NOTES: (1) Equipment depth only.

(2) Surface mounting of system possible with ramped approach.

(3) Grades will be subject to A17 Code limitations, 12-30% is commonly accepted industry maximum for conventional constant speed walkways.

out of the Speedaway at its ends is another dimensional constraint which requires significant clear space. A bi-directional system with two parallel units would increase this requirement.

The TRAX and Boeing bi-directional loop systems have similar dimensional requirements. Because of the loop configuration, each requires a site with relatively wide clear space, but the space in between the walkways could be used for a sidewalk. Because the pallets for each of these systems are returned on the surface, a relatively shallow depth is possible for these systems, offering the potential of surface mounting. Greater depth is required at the ends of the TRAX system for a machine room and pallet turning purposes. The Boeing end chamber requirements would be less as presently configured. Reportedly, each of these systems could adapt to limited horizontal and vertical curves and grade changes.

A siting characteristic of all variable speed accelerating moving walkway systems, which limits their installation in on-grade installations is the frontage or barrier affect. An at grade AMWS blocks intersecting pedestrian pathways not running parallel to its alignment, similar to guideway or other exclusive right-of-way transport systems. As with other transportation systems, grade separation, either above ground on a pedestrian bridge, or underground in a pedestrian passageway, removes this restraint.

3.2 Passenger Service Characteristics

The utilization of an AMWS will be dependent on its adaptability to the transportation demand and traffic patterns in the intended application, as well as passenger acceptance of riding characteristics. Accelerating variable speed moving walkways are continuous service systems offering advantages over vehicular batch load systems in many applications. These advantages are discussed in greated detail in Report C of the AMWS study series. Photographic studies of the passenger utilization of escalators and moving walks have indicated that practical operating capacity is related to available entry or portal width and the characteristics of the user population, including such factors as individual psychological preferences to avoid crowding and contact with others. [Ibid. 2] Treadway speed is less of a determinant of moving way system capacity, since the capacity limitation appears to be a human, rather than mechanical, restraint. Even under the heaviest traffic demand pressures, it is consistently observed that only 60-70 percent of the available step positions are occupied on escalators. Productivity comparisons between 90 and 120 fpm (27-37 mpm) escalators show only about a 10 percent increase in utilization with the one-third increase to the higher speed. Other studies show optimum escalator capacity occurring at about 145 fpm (44 mpm), after which use levels off. Reportedly, speeds of up to 180 fpm (55 mpm) are used in the Leningrad, Russia subway system but no productivity or safety data is available. It is common practice in the United States to run many moving way systems at the lower 90 fpm speed, such as in department stores, where demands are not heavy and where the user population is comprised of greater proportions of the elderly, or those encumbered by packages. Additionally, trip times are less of a premium in these situations.

Since the entrance portal configuration for all but the Speedaway variable speed walkways is comparable to existing conventional escalators and moving walks, it is assumed that their effective capacity will be equivalent to approximately 3600 persons per hour per 24 inches (610 mm) of width measured over the handrails. The Dunlop Speedaway system represents a special case since the treadway width at the entry portal for the 1:5 speed ratio system will be 9.75 feet (2.98 m). Higher potential occupancy would be possible with this system since it would be theoretically possible for 5 persons abreast to board the system. However, as a practical human factors consideration, it will be desirable to channelize pedestrian traffic to assure passenger proximity to a handrail, thereby resulting in only two effective approach lanes.

Other performance characteristics affecting the public acceptability of variable speed walkways will be user adaptability to treadway alterations. With the exception of the Dunlop Speedaway system, which uses individual pallets similar to an escalator, AMWS users will encounter a changing treadway surface beneath their feet, either in the form of diverging and converging leaves, grooved intermeshing pallets, or steel rollers of varying speeds. The standing surface alteration will be a new sensation which some users may find to be objectionable. Additionally, motion affects of acceleration, deceleration, and the rates of change of these motions will be encountered, but this is commonly experienced on all modes of transportation. An objective of the AMWS public demonstration is to closely observe through photographic techniques and analysis, the affects of these motion characteristics on various categories of users, including the elderly and handicapped.

The desirable standards for acceleration, deceleration and rates of change of acceleration and deceleration, based on Project Consultant recommendations as well as other data, are developed in detail in Report C of the Project study series - "AMWS - Safety and Human Factors". It should be emphasized that the acceleration and deceleration of any of the systems is not locked into their design, and can be changed to meet the specifications of the equipment purchaser. A consideration will be the recommended speed and other motion specifications of the special ANSI A17 sub-committee on accelerating variable speed moving walkways.

Table 3.2 following summarizes reported accelerations, decelerations, and rates of change of these functions for the five prototypical systems. Each of the systems is capable of attaining the 1:5 speed ratio considered desirable for a demonstration mode AMWS. Effective passenger capacity for all linear systems is estimated at about 7200 passengers per hour on the assumption of a 40 inch (1016 mm) treadway. The Dunlop Speedaway system, with its wider entrance treadway configuration, would have potentially higher capacity depending on the purchasers priorities for user handrail proximity. Table 3.2 also summarizes the relative familiarity and ease of use of the respective systems.

ACCELERATING MOVING WALKWAY SYSTEMS

PASSENGER SERVICE CHARACTERISTICS (1)

TABLE 3.2

	ITEM \ MODEL	DUNLOP SPEEDAWAY	RATP TRAX	JOHNS HOPKINS A.P.L.	BOEING	DEAN RESEARCH
1.	Acceleration/ Deceleration (2)	.04 G	.10 G	.08 G	.12 G	.07 G
2.	Rate of Change (RCA) Accel./Decel. (2)	.04 G/sec.	.06 G	.06 G	.10 G/sec	N.A.
3.	Emergency Deceleration (2)	.10 G	.20 G	.15 G	.20 G	N.A.
4.	Overall Familiarity	Wide curved entrance unlike escalator, multiple 7 section handrail, transverse shift of pallets may confuse some.	Entrance and treadway configuration similar to escalator, handrail grip, and handrail end condition unlike escalator.	Entrance and treadway configuration similar to escalator, accordion type handrail unlike escalator	Entrance and treadway configuration similar to escalator, telescoping handrail unlike escalator	Entrance configuration similar to escalators, but rollers unique. Handrail details N.A.
5.	Treadway Surface Changes	Standing surface stable, transverse shifting of pallet.	Sliding of intermeshing grooved pallets beneath feet.	Unfolding, folding rounded leaf surfaces beneath feet.	Sliding of intermeshing grooved pallets beneath feet.	Multiple variable speed roller movement beneath feet.
6.	User Learning Task	Avoid straddling two pallets or standing on pallet tabs, shift of body position to direction of motion, use 7 section handrail.	Adapt to surface changes, hold handgrip, maintain proper spacing to avoid passenger bunching.	Adapt to surface changes, handrail shape, maintain proper spacing to avoid passenger bunching	Same as A.P.L.	Adapt to rollers. Handrail details N.A. Bunching minimized since tread does not contract.

NOTES: (1) Attainable speed ratios for all systems assumed 1:5, working capacity 3600 passengers per hour per effective pedestrian lane (24" over handrails).

(2) Not an inherent system restraint, can be changed to suit purchasers' requirements; G = 32 ft/sec^2, 9.8 m/sec^2/

(3) N.A. - not available.

3.3 AMWS Costs

Accelerating variable speed moving walkway systems will provide cost effective solutions to transportation problems where traffic volumes are sufficiently high to warrant installation, and where alternative systems would be more costly in terms of installation, operation, and total life cycle costs. The primary cost advantage of variable speed moving walkways is their operational simplicity and concomitant lesser manpower and skills requirements. The manned vehicular alternative requires operating and repair personnel, as well as facilities for the garaging and maintenance of vehicles. Automated vehicular systems generally reduce total manpower requirements, but job skills shift into categories requiring higher levels of training such as electronics. Properly maintained moving way systems will have service lives exceeding 25 years. Repairs are mechanically simple, involving replacement of basic parts such as chain linkages, rollers, pallets, handrails, combplates, etc.

Capital costs for an AMWS include the furnishing and installation of the unit and the structural, architectural, and electrical system preparation of the installation site. Operating costs would include costs of power, insurance, maintenance personnel, and supplies. Additionally, heating, ventilation and air conditioning may be required in some installations. Definitive costs for the furnishing and installation of an AMWS have not yet been determined because of the lack of production experience. Conventional escalators and moving walks currently cost between $1000 and $1200 per lineal foot ($3280-3940/m) for furnishing and installation of a unit at the site. Accelerating moving walkway hardware does not differ substantially from that of existing conventional escalators and walkways, suggesting that an early production unit AMWS should be on an order of magnitude of about 50 to 100% greater cost for furnishing and installation, or about $1500 to $2400 per lineal foot ($4920-7870/m). Naturally, the effective system route length for estimating the cost of a bi-directional loop unit would be approximately double that of the one-directional unit.

Structural and architectural preparation costs for the various systems vary according to the installation envelope comprised of the sub-grade depth requirement and height and width of the system. Shallow depth, one-directional linear systems would be the most cost effective where only a single reversible "tidal flow" traffic direction was being served, for example at a sports complex. Preparation costs would also vary according to whether the AMWS was installed on grade, elevated on a pedestrian bridge, or undergound in a pedestrian subway.

Energy use and power cost on a passenger carried basis for accelerating moving walkway systems is less than vehicular transit because the weight carried is greater in these systems (vehicle and passenger), and because of the elimination of energy losses such as braking associated with vehicular operation. Insurance costs for an AMWS is currently estimated to be comparable to that of an escalator since it is not anticipated that user risk will be any greater. A cost benefit evaluation of an accelerating moving walkway installation is contained in Project Report D. Approximate preliminary estimates of relative system costs are contained on Summary Table 3.3, following.

ACCELERATING MOVING WALKWAY SYSTEMS

PRELIMINARY COST DATA

TABLE 3.3

ITEM \ MODEL	DUNLOP SPEEDAWAY *	RATP TRAX *	JOHNS HOPKINS A.P.L.	BOEING	DEAN RESEARCH
1. Estimated Cost Equipment (Ex-Factory)	(one direction)	(two direction)	(one direction)	(two direction)	(one direction)
a. 300 ft. (91 m)	$ 707,200	$1,500,000	$ 487,000	$ 690,000	$ 600,000
b. 500 ft. (152 m)	$ 966,450	$2,000,000	$ 692,000	$ 950,000	$ 875,000
c. 1000 ft. (305 m)	$1,614,150	$3,000,000	$1,200,000	$1,600,000	$1,500,000
2. Estimated Site Preparation Cost (2) (per lineal foot)		Note (3)			Note (3)
a. covered, at grade	$1860/L ft.	$1430/L ft.	$1360.L ft.	$1430/L ft.	$1360/L ft.
b. covered pedestrian bridge	$2580/L ft.	$2650/L ft.	$2240/L ft.	$2650/L ft.	$2240/L ft.
c. below grade pedestrian subway	$4250/L ft.	$4020/L ft.	$3330/L ft.	$4020/L ft.	$3330/L ft.
3. Estimated Demand KW, Loaded, Cost per Running Hour (4)					
a. 300 ft. (91 m)	90 KW ($ 4.50/hr)	50 HP/ 67 KW ($3.35/hr)	30 HP/ 40 KW ($2.00/hr)	50 HP/ 67 KW ($2.50/hr)	N.A.
b. 500 ft. (152 m)	120 KW ($ 6.00/hr)	70 HP/ 94 KW ($4.70/hr)	50 HP/ 67 KW ($3.35/hr)	70 HP/ 44 KW ($4.75/hr)	
c. 1000 ft. (305 m)	200 KW ($10.00/hr)	100 HP/134 KW ($6.70/hr)	100 HP/134 KW ($6.70/hr)	120 HP/160 KW ($8.00/hr)	

NOTES: (1) Based on manufacturers replies to Project questionnaire, equipment costs only.

(2) Based on Port Authority Engineering Department estimates, assuming favorable site conditions.

(3) TRAX based on estimate for BOEING; DEAN based on estimate for APL.

(4) Energy cost based on $.05 per kilowatt hour.

* Dunlop and RATP assume $ conversion rate at mid '77.

3.4 Developer Qualifications

A factor determining the prospective supplier of a variable speed accelerating moving walkway system for a public demonstration will be the qualifications of the supplier to manufacture and install the AMWS according to project specifications, costs and schedules, and to provide technical and logistical support for the public use demonstration. A positive feature of moving way systems, including variable speed accelerating moving walkways, are their basic mechanical simplicity. This will simplify field installation problems, system shakedown, and maintenance. If necessary, well established mechanical engineering consultants are available to assist AMWS developers having limited experience with local construction, institutional and labor practices.

The Dunlop Corporation, developer of the Speedaway system is qualified to manufacture a demonstration unit and to provide the necessary technical and logistic support because of its extensive experience as a manufacturer of conventional escalators and moving walks in Europe. Furthermore, the manufacturer has operated prototype and near production units in its factory, gaining valuable experience in system production and maintenance. Dunlop could encounter minor difficulties because of inexperience with U.S. construction practices, but this problem is not considered significant.

The Regie Autonome de Transports Parisiens (RATP), developer of the TRAX system, is a transportation authority with extensive experience as an owner-operator of conventional escalators and moving walks, but no direct capabilities to manufacture and support the demonstration. RATP has retained a consultant specializing in locating

United States firms as licensee manufacturers of foreign products, so that it can be anticipated that a qualified supplier can be found for the TRAX system. RATP running experience with the TRAX system, plus its experience with its own conventional walkway systems provides a good technical background for the demonstration support task.

Johns Hopkins University, Applied Physics Laboratory, developers of the "APL" system have a well-established reputation for technical competence in research and development, but no capabilities to manufacture a demonstration AMWS system, nor to supply maintenance support. The University would require a manufacturer to produce a demonstration unit and provide the necessary logistic support. A licensee agreement with an established escalator or moving walk manufacturer, or other similar agreement, could probably satisfy the supplier qualifications requirement.

The Boeing Corporation has a well established reputation in aerospace and transportation system research, development, manufacturing, and installations, but no direct experience with moving way system manufacturing and installation. As noted previously, installation experience is not considered to be a critical factor because of system simplicity and the availability of competent consultants and contractors in this area.

The Dean Research Corporation, developers of the roller system, have experience with the manufacturing and installation of industrial conveyors, but no known experience with the construction trades and jurisdictions normally involved in escalator and moving walk installation.

This is not an insuperable qualifications factor, but would require assurance of adequate financial backing for a venture of this magnitude and duration.

3.5 Safety and Human Factors

The safety and human factors of variable speed moving walkways has been developed in detail in the C Report of the Project series - "Accelerating Moving Walkway Systems - Safety and Human Factors". The report concluded that based on an overview of transportation safety, an identification and evaluation of possible AMWS hazards, an analysis of moving way accident experience on conventional escalators, the reports of safety consultants retained as part of Project, as well as the result of a special Project Safety Seminar, that there appeared to be no reason, apriori, why an AMWS cannot be operated in a public demonstration mode at acceptable levels of safety. The conclusions of the report were founded on the assumption that a basic safety program is followed for the public use demonstration addressing human factors characteristics and equipment design, equipment operation and maintenance, prior instruction of passengers in correct use, the demonstration environment is appropriate and controls are maintained that assure proper use of the system.

The C Report developed six potential accident risk categories that are associated with the operation and use of accelerating walkways. These risk categories have been termed (1) inertial, (2) entrapment, (3) divergence and surface discontinuity, (4) bunching, (5) post problems, and (6) mechanical failure. An additional potential risk would be individual physiological or psychological responses to the equipment movement, possibly in combination with characteristics of the environment, equipment finishes, and lighting, motion and stroboscopic illusions, or other similar disorienting effects.

The inertial hazard refers to the movement forces places on the user by the acceleration, deceleration, the rate of changes these factors, and emergency stopping. Coriolis is another motion affect, not associated with the candidate systems, but present in systems using turntables or other devices involving circular movement paths to accelerate or decelerate passengers. Too rapid acceleration or deceleration could cause AMWS passengers to lose their footing and fall, unless the fall is arrested by grasping a handrail.

The entrapment hazard is common to all moving machinery and involves the catching and possible ingestion into the equipment of clothing, footwear, or human extremities. Possible entrapment hazards with the systems reviewed in the assessment will exist at combplates and other types of transitional surfaces similar to those of existing conventional walkways. Additional entrapment potential may also exist at the intermeshing treadway surfaces characteristic of the APL, TRAX and Boeing systems, and where the smooth triangular pallet surface edges retreat beneath the stationary balustrade in the deceleration section of the Dunlop Speedaway. AMWS handrails may also offer possibilities for entrapment as they converge in deceleration sections or where hand grip designs have features that might catch clothing or purse straps, or where the handrail return configuration, at the point where the handrail enters the balustrade, is improperly designed or located.

Divergence is defined as a displacement or differential in treadway or handrail speed or direction. Discontinuities are interruptions in treadway or handrail surfaces. Examples of divergence and discontinuity problems on conventional escalators and moving walkways exist at the entry and exits where it becomes necessary for the user to adjust to differentials between stationary pavement surfaces and the equipment's moving treadway and handrail. The escalator presents another divergence and discontinuity problem with its emerging stepped risers, causing the upsetting of riders who stand on the line between two treads as they shift into the stepped stairway configuration. Several divergence and discontinuity situations have been identified on the systems under review in this report. Some systems are not sufficiently developed, or have components that are not yet developed for meaningful comparisons. The Dunlop Speedaway system will require adjusting hand positions for its sequence of seven handrails as well as for a differential in the handrail speed relative to the treadway. Shifting treadway positions, or more accurately the shift in the facing direction of the rider relative to the direction of movement on the system, may also disorient some users of the Speedaway. Expanding and contracting handrails and treadway surface configurations on other systems will also create differentials between hand location relative to standing position, requiring adjustment of user hand and/or body positions.

Divergence and discontinuity situations are mainly an accident hazard for inattentive users, those under the influence of alcohol or drugs, or segments of the elderly and handicapped with impaired perception and reaction capabilities. Persons with obscured views of handrail or treadway surfaces due to dense pedestrian traffic or hand carried packages may also experience some difficulty adjusting to divergence and discontinuity situations.

Bunching may be defined as the crowding of pedestrians to such an extent that their free movement is restricted. Bunching is considered to be a potential hazard on Accelerating Walkways because of the treadway contraction and reduction of surface area in the deceleration section of these systems. Under certain pedestrian traffic conditions, bunching could cause a dangerous jamming or pile up. The bunching problem exists on the TRAX, APL and Boeing systems because of the 5:1 contraction of the treadway surface in their deceleration sections. Bunching also occurs to a limited and less critical degree on the Speedaway in the deceleration section where pallet ends move beneath the balustrade. The Dean roller system is not considerd to present a bunching problem because the treadway surface does not contract. User education, visual and audial warnings, more formalized indications of correct standing positions, and other control strategies will be required to minimize the prospects of bunching on accelerating walkway systems with high ratios of treadway contraction.

The post problem can be described as the presence of any stationary object or design feature along the system or at its outlet which protrudes into the walkway plane from the sides, or from above, situated in such a way that it could come in contact with moving passengers. Protruding moldings or other irregularities in the balustrade surface can cause post situations by catching packages, shopping carts, etc. and thereby impacting the rider and possibly throwing him off balance. Serious post problems have not been identified with the system reviewed in the assessment as currently existing, but as these systems advance from the relatively unfinished prototype stage, design features such as balustrade configurations will have to be carefully reviewed to determine if post hazards exist.

Mechanical failure risks occur where components of a system fail in a manner hazardous to passengers. As part of the design development, manufacture and testing, and procurement phases of the Project, the potential failure modes of each element of candidate systems will require identification, and the potential consequences of this failure on rider safety evaluated.

A preliminary summary of hazard categories for the five systems under consideration, in this report, based on the amount of equipment details available as of the date of the report, is contained on Table 3.4 following.

AMWS EQUIPMENT HAZARD SUMMARY

TABLE 3.4

HAZARD CATEGORY

SYSTEM	INERTIAL	ENTRAPMENT	DIVERGENCE	BUNCHING	POST PROBLEM	MECHANICAL FAILURE	HANDICAPPED CONSIDERATIONS
DUNLOP SPEEDAWAY	Design objective is to meet motion criteria. Handrail proximity is factor at entry and exit.	Equipment tolerances standard, conventional combing at ends, shearing concern for pallet beneath balustrade at deceleration section, multiple handrail detailing may increase entrapment probability.	Segmented handrail/treadway speed differentials transverse displacement adjacent treads.	Minor, minimized by expanded area deceleration section.	Handrail transition detailing is stationary feature.	No abnormal hazard identified, missing pallet protection desirable.	Multiple handrail grasp and release, handrail proximity, transverse movement treads, handrail and tread speed differences
TRAX	Design objective is to meet motion criteria.	Conventional combing at ends and at intermeshing treadway, surfaces, handrail detailing not sufficiently developed.	Synchronicity of handrail and treadway expansion and contraction.	Decrease in treadway area in deceleration zone proportioned to speed ratio.	Not identified. Complete equipment detailing unknown.	No abnormal hazard identified, missing pallet protection desirable.	Expanding, contracting handrail and treadways will require foot and hand position adjustments.
APL	Same as above.	Same as above, plus rotative action of leaves during accel. and decel. may entrap.	Synchronicity of handrail and treadway expansion and contraction.	Same as above.	Same as above.	Same as above.	Same as above.
BOEING	Same as above.	Same as TRAX.	Same as TRAX	Same as above.	Same as above.	Same as above.	Same as above.
JEAN RESEARCH	Same as above.	Combing detail unknown, rollers are of torque limit design, potentially reducing entrapment hazard. Handrail detailing unknown. Rollers may build up friction coating film in use increasing entrapment.	Treadway does not contract, speed differential adjacent rollers. Handrail configuration not defined.	Treadway does not contract, speed differential of rollers will potentially contribute to some bunching.	Same as above.	Roller seizure could cause tripping hazard.	Handrail configuration not defined.

A P P E N D I X

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7. Todd, J. K. - "The Dunlop Speedaway - A High Speed Passenger Conveyor" - Intersociety Conf. on Transportation, July '76, 8 pp. Problem of large volume movement over relatively short distances has not been addressed, speed present moving walks too slow, discusses combing, post problems in line AMWS, describes Speedaway system, evaluates benefits.

8. Mehmi, A., Ayers, K. B. - "Design of High Speed Moving Pavements for Mass Transit" - TT 7410, Loughborough University of Technology, Oct. '74, 139 pp. Summary of characteristics of various proposed AMWS systems, including disadvantages; proposed development of a system using sliding lenticular pallets, similar to Speedaway system; recommended acceleration/deceleration rates 1.77 ft/s^2; computer designed tread geometry.

9. Blevins, R. W. (et al) - "Variable Speed Walkways" - Elevator World, May '76, pp. 25-99. Description, data Johns Hopkins, APL AMWS.

CHRONOLOGICAL HIGHLIGHTS

VARIABLE SPEED CONTINUOUSLY MOVING WALK DEVELOPMENT

1874 U.S.A., Speer's Moving Pavement Proposal for N.Y.C., 20 km/hr moving platform propelled by steam driven wheels riding on a track. Boarding and leaving from six seat trolleys running parallel and adjacent to moving platform using friction drive to platform.

1887 U.S.A., Pearson's Concentric Ring Platforms proposed to use a number of large concentric platforms turning in same direction but at differential speed. Slowest platform in center, outer platform fastest and used to board contiguous train running at matching speed.

1888 Germany, Rettig's Stepped Train Patent, several parallel and adjacent moving platforms running at 5.3, 10.8 and 16.2 km/hr with passengers stepping from one platform to the next. Hand posts fitted to slower platforms, seats to fastest platform. Platforms ran on wheels on tracks with cable propulsion.

*1893 U.S.A., Silsbee and Schmidt, Chicago Moving Platform for 1893 World's Columbian Exposition - Two contiguous platforms operating at 3 mph and 6 mph. Elliptical layout 1310 meters long. Wheels of slow platform ran on rails and electrically powered. Fast platform mounted on rails which were propelled from the top of the slow platform wheels giving a 2/1 speed differential. Capacity 31,680 pass./hour.

*1896 Berlin, Moving Platforms, similar to 1893 Chicago installation, 460 meter system dumb-bell shaped.

1896 France, le Boul's Rotating Pier, proposed 30 meter diameter rotating platform, open at center where passengers entered by stairway, and transferred at the circumference to a continuously moving chain of trucks carrying seats. Principle eventually used in 1964 Swiss National Exhibition for Telecanape Railway.

1898 Germany, Vietors' Epicycloidal Railway. Loading disc rotated between stationary central circular platform and a moving annular platform.

*1900 France, Blot/Guyenet/de Mocomble 1900 Paris Exposition, 3.3 km long, with endless chain of flat trucks operating on two parallel and adjacent tracks at speeds of 3.6 km/hr and 7.2 km/hr respectively. Electrically powered. Carried 6.694 million passengers.

1904 U.S.A., 34th Street, N.Y.C. proposal for four platform system moving at 0, 3, 6 and 9 mph in parallel arrangement with capacity of 48,000 pass/hr. Proposed from 1st Avenue to 9th Avenue. Opposed by Metro Street Railway Co. Platforms rode on wheels on tracks, electrically powered.

⊕1923 U.S.A., Putnam's N.Y.C. 42nd Street Proposal for end looped subway system from 3rd Avenue to 8th Avenue to replace subway shuttle service. Parallel platforms moving at 3, 6 and 9 mph. Seats on fastest platform. Powered by linear induction motors (LIM). Capacity 35,640 pass/hr. Elliptical demonstration system built and operated in Jersey City.

1924 France, City of Paris, proposal in competition for new system to supplement Metro. Ten mph continuously running platform (with seats) boarded from interlocking cascade of belts, which accelerated from 1 1/2 to 10 mph. Full scale tests indicated accelerating/decelerating sections would be each 30 ft. long for standing passengers, resulting stations were too long, therefore not installed.

1935 U.S.A., Storer/Westinghouse Bi-Way System of two parallel moving platforms. Local platform accelerated from zero to 24 km/hr at which speed it matches speed of express platform. Proposal only.

1956 U.S.A., Pfeiffer's cascade of stretchable rubber belts proposal to provide acceleration/deceleration ability.

1964 U.S.A., Bell Synchroveyor. Loop within loop conveyors. Inner loops are variable speed, outer loops constant speed. Transfers made at synchronous speed. Proposal only, electro-mechanically driven.

●1964 Switzerland, Bouladon/Batelle Continuous Integrator. Transverse entry/exit at safe speed combined with longitudinal acceleration and deceleration to provide 3/1 to 5/1 variable speed ratio conveyance of standing passengers. Basis of subsequent 'Speedaway' system development by Dunlop in England.

1966 U.S.A., Ayres & McKenna Veriflex deformable diamond mesh walk to provide 5/1 to 6/1 speed variation. Mesh belting roller supported at edges and propelled by electrically powered cable, chains or screws. In model form only.

●1969 U.S.A., Blevins/A.P.L. Variable Speed Walkway, 3/1 to 5/1 speed ratio, Variable geometry overlapping comb leaves, chain linked and operating on variable pitch electrically driven screws. Leaves run on rollers in supporting tracks. Ten meter lab. demo completed.

1969 U.K., Turner's Lenticular Accelerator, in which lenticular shaped (convex and concave) platforms are employed in a similar manner to Bouladon system except it has the ability to change direction without speed change and vice versa.

1970 France, Engins-Matra Tras. 18. Endless belt of rods forming deformable diamond mesh covered with bed of overlapping metal plates. 5/1 speed ratio. Electrically driven. Mock-ups, models and small moving section built.

1970 France, RAPT TRAX. Endless loop system of comb and groove plates which shorten and lengthen to provide 4/1 speed ratio. Electrically driven with chains, gears and links, 70 meter prototype test/demo unit under development.

197? Germany, Krauss-Maffei Transurban Conveyor comprising inner disc at ground level serving as rotary lift to inside of rotating disc. Passengers move to perimeter to transfer to a constant speed (13 km/hr) walkway. Concept and model.

1971. U.S.A., Georgia Institute of Technology Accelerating Belt. Student project proposal for Downtown Atlanta Radial Study. Overlapping plates linked together. Overlap increases as speed increases. Electrically driven with hydraulic damper linkage.

1971 U.K., Cranfield Institute of Technology, Travelling Wave Walk. Flexible tube nipped by roller to form seal. When tube inflated pressure exerted on roller propels it along the tube. Concept and modelling.

1973 U.K., NRDC Scimitar Pavement. Scimitar shaped, tapered and curved pallets similar to 'Speedaway' concept except that it can negotiate curves.

1975 U.K., Mann's Crestwalk passenger conveyor of overlapping pallets supported and guided by tracked rollers and propelled by LIM which imparts acceleration, high speed and deceleration cycles to pallets and which gives small phase difference in the cycles between adjacent pallets. The result is to produce areas of increased speed. If the passenger walks forward he will remain on a speed crest. If the passenger stops walking, he will reach safe alighting speed. Concept only.

? U.S.A., Candella Variable Speed Belt is an accel./decel. moving belt where the effective belt length varies, increasing as speed increases and vice versa. The belt is wrapped over sets of rods which ride on end rollers in side tracks to accomplish this. Concept only.

? U.S.A., Jackson and Moreland Oscillating Elastic Apron Proposal.

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*Built and operated in public

●Demonstration unit built and operated.