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United Engineers and Constructors ● Raytheon Equipment Division
Failure Analysis Associates ● Bromwell & Carrier
Beech Aircraft Corporation ● Process Systems International

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SYSTEM CONCEPT DEFINITION REPORT
for the
NATIONAL MAGLEV INITIATIVE

Volume
1

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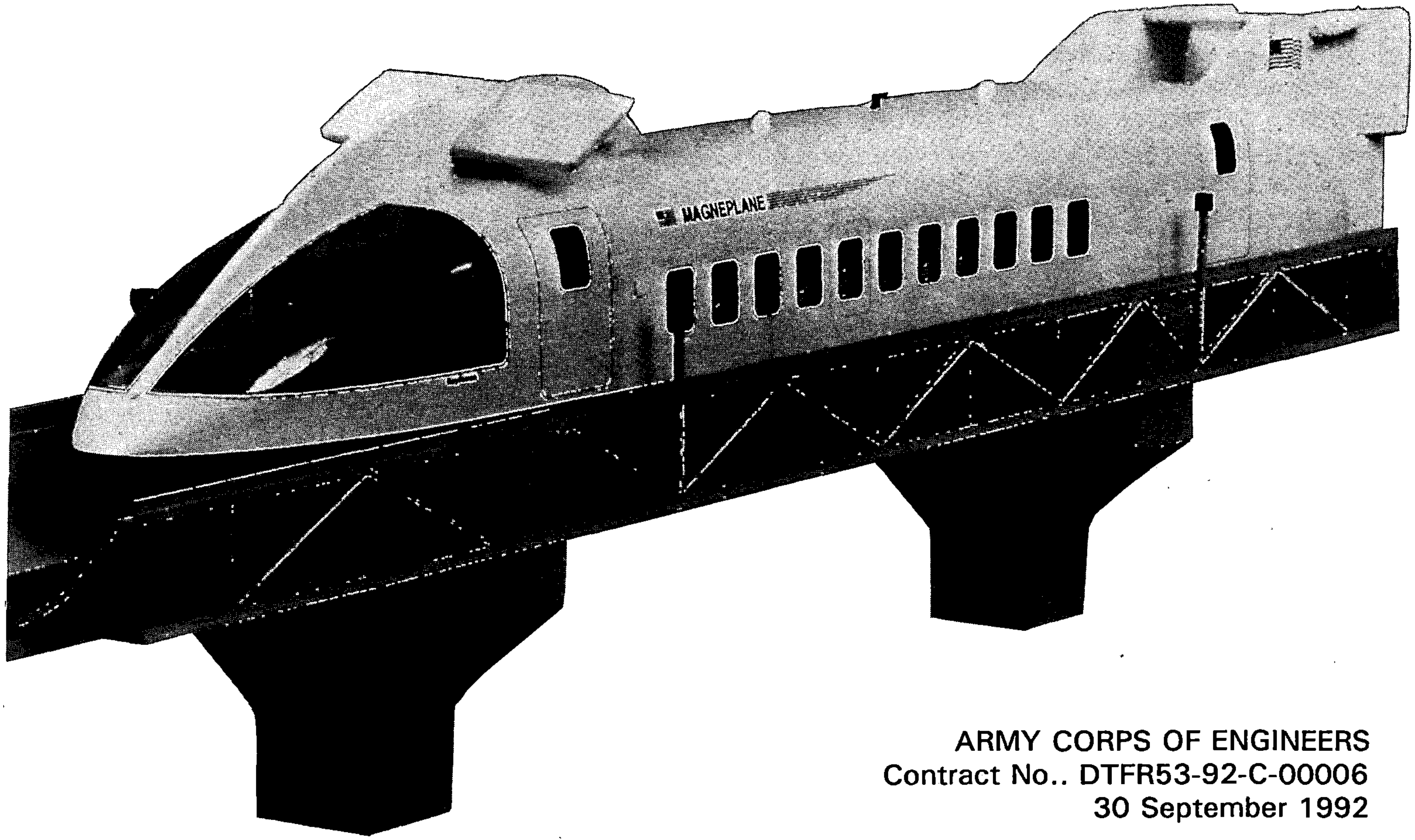

ARMY CORPS OF ENGINEERS
Contract No.. DTFR53-92-C-00006
30 September 1992

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INDEX TO VOLUMES

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EXECUTIVE SUMMARY

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1. DESIGN OVERVIEW

1.1. MAJOR MAGNEPLANE DESIGN GOALS

Existing transportation technology is nearing saturation and cannot meet projected demands. Airlines have saturated the airspace at major hubs. Automobiles will require 40-lane interstate highways in a decade. Railroads, whether wheelborne or maglevitated, can handle about half as many passengers as one single highway lane; the faster they go, the less their capacity, and the less often they can stop. Radically new technology is needed.

The next revolution in transportation technology has begun, and will become the largest technology venture for several decades. Our economic security requires that we play a leading role in this venture, world-wide.

Magneplane International is designing the only transportation system proposed thus far that can meet projected demands, and help solve the problems of existing technology: *congestion, pollution, environmental destruction, dependence on foreign oil, and unnecessary loss of lives.* Magneplane therefore offers the only technology which can restore US leadership in transportation.

Magneplane's objective is not only to replace short-haul airlines, but primarily to reduce highway traffic, which carries more than 90 percent of passengers and freight along most corridors. This means providing a cost-effective, attractive alternative that people will actually use instead of their cars. If the automobile is partially displaced by a faster, safer, cheaper means for travelling and commuting, driving will be fun again, and we can better protect our health and environment. Magneplane systems will permit measures like the establishment of green-belt zones to revitalize urban centers by reduced congestion, frustration and lost productivity.

Magneplane technology will also enable the United States to develop world leadership in high-speed ground transportation, thereby restoring our balance of trade, our industry, and our jobs.

Our principal design goals are the following:

1. *cruising speed of 300 mph, high average speed, low waiting time, non-stop service when possible*
2. *capacity of up to 25,000 passengers per hour on a single magway (equal to three highway lanes)*
3. *transportation alternative to both cars and planes for trips as long as 400 miles*
4. *ride quality as good or better than airplanes*
5. *safe, reliable, and operational under all weather conditions*
6. *no new corridors - should be built along existing highways*
7. *flexibility in upgrading capacity and service*
8. *points of access where people live and work, lower use of intermodal connections than required by airplanes*

1.2. HOW OUR DESIGN MEETS THESE GOALS

We propose a computer-controlled continuous flow system:

- We will build **small magports** at shopping malls, industrial parks, city centers, and any other place where people go in great numbers. There is no reason to limit maglev use to a few huge hubs. Small off-line magports will be served without interrupting the flow of magplanes along the principal corridor.

- We will connect the stations with a network of **magways built along existing highways.** New land for straight routes is simply not available in places where maglev is needed most. The Magneplane system allows magplanes to bank in curves like airplanes to provide a comfortable ride at high speeds.

- We will run **single magplanes,** not trains. Magplanes will be dynamically scheduled: A central computer will plan the routes of each vehicle in response to ticket purchases, so that passengers will get fast service directly to their destination with as few stops between as possible. With long trains, small magports are not possible, nor is dynamic scheduling. Trains cannot stop often enough to be useful.

The magplane is propelled by a powered magway; vehicles ride a travelling wave, like surfboards; they can follow at close headways without colliding. Super-conducting magnets on board the vehicle interact with the magway to produce both lift and thrust.

1.3. LEVITATION 3.2.1.a.

Superconducting levitation magnets at the bow and stern produce strong magnetic fields underneath the vehicle. When the magnets move, their fields induce image currents in a 2 cm thick aluminum sheet in the magway. These image currents behave exactly like mirror images moving with the vehicle magnets, and therefore repel them, producing a lift force.

Not true

Sheet levitation (as the effect has been called) can produce a smooth ride at a height of several inches above the magway, even when the magway is rough. This magnetic spring is very soft, but becomes very stiff as the vehicle is pushed toward the magway and thus prevents contact. Oscillations are prevented by an active damping system (smart shock absorber) described below.

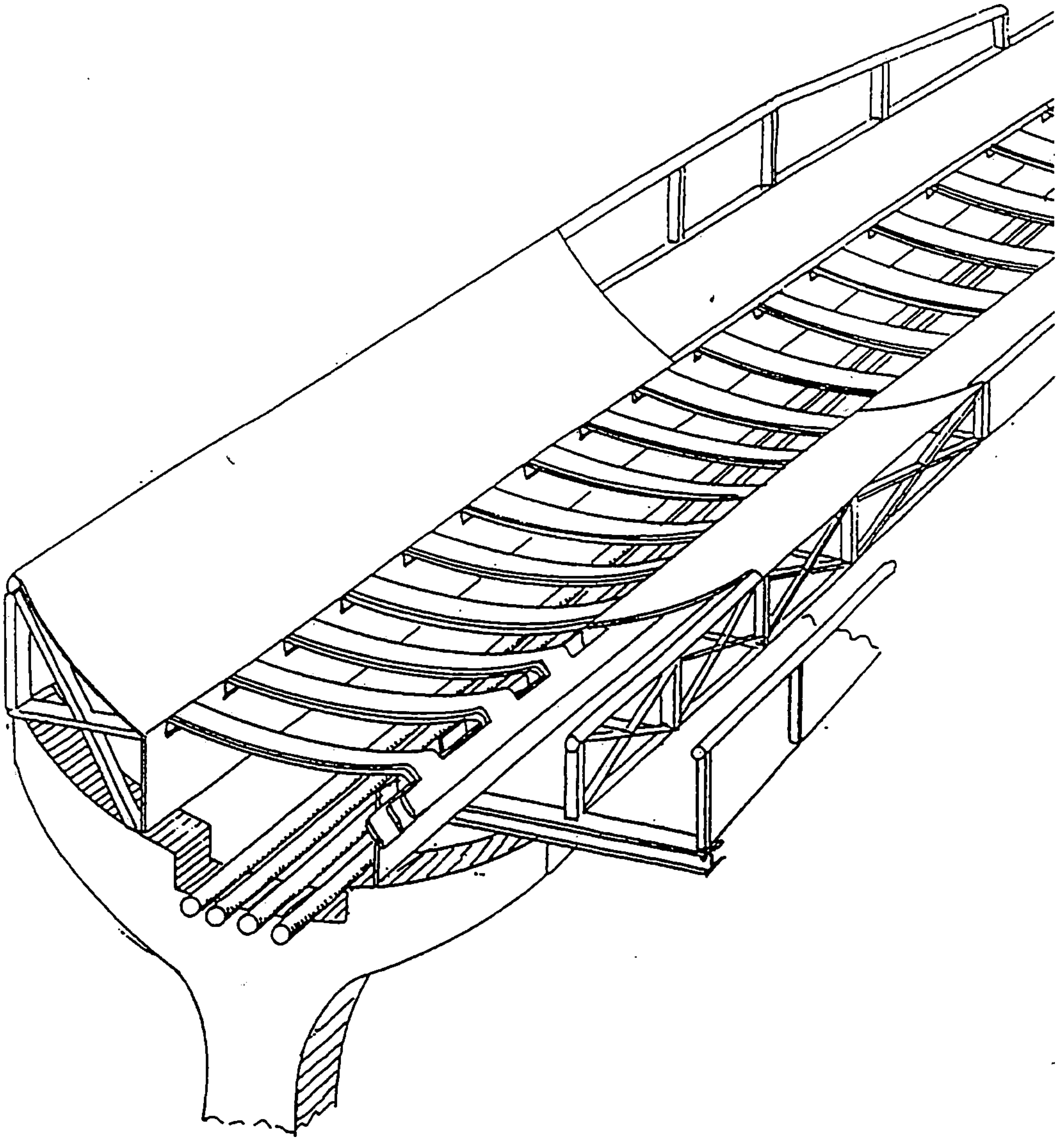

Figure 1 Isometric view of magway showing structure, LSM windings, and levitation sheet

1.4. PROPULSION AND BRAKING 3.2.1.b.

The Magneplane vehicle is propelled by a *linear synchronous motor* (LSM), which resembles a "brushless DC motor", stretched out along the magway. In a rotary motor, a rotor with coils follows a rotating magnetic field generated by stator coils which surround the rotor.

In the case of Magneplane, the rotor coils are aboard the vehicle, and the stator coils are in the magway. When they are powered with AC current, the magway coils produce a *traveling wave* of magnetic field. The speed of the wave depends on the frequency of the AC current. This frequency, and thus the vehicle speed, is controlled by wayside power units which resemble the wayside transformers in a conventional railroad. These units can accelerate, maintain speed, or decelerate the vehicle.

Each unit powers the LSM over a block of up to 2 km. Only one vehicle occupies a block at any given time, so there are never two vehicles riding the same traveling wave.

The wayside power units communicate with the magplane travelling in their particular block, controlling its speed. They also communicate with the central controller which manages all traffic in the entire system.

1.5. MAGWAY 3.2.2.a.

The Magneplane magway can be built on grade. It can also be elevated inexpensively because it carries only one twentieth the live load of a railroad trestle. This is an important advantage, because grade crossings cannot be used at the speed and frequency of magplanes.

The upper surface forms a circular trough designed for passive self-banking in curves (see below). The trough consists of three parts: The center contains the linear synchronous motor winding, which is a meander coil potted in reinforced composite; It is flanked on each side by a curved aluminum levitation plate forming a trough of circular cross section. This trough is supported by an integral aluminum space frame, or where long spans are necessary by a separate girder of concrete or steel.

1.6. COORDINATED CURVES 3.2.1.e.

Magneplane vehicles can perform *coordinated curves,* just like airplanes. A perfectly coordinated curve is a banked curve in which there is no sideways force on the passengers - they are not aware of any banking unless they look out the window. Coordinated curves happen automatically in the vehicles because they are free to roll in the circular magway trough, and the vehicle's own mass provides the rolling moment.

Curved magways are built for a particular optimal speed (the design speed) at each point. At the design speed, the vehicle rolls such that its propulsion magnets are directly over the linear synchronous motor windings. Significant deviation from the design speed is acceptable, without a loss of propulsion power

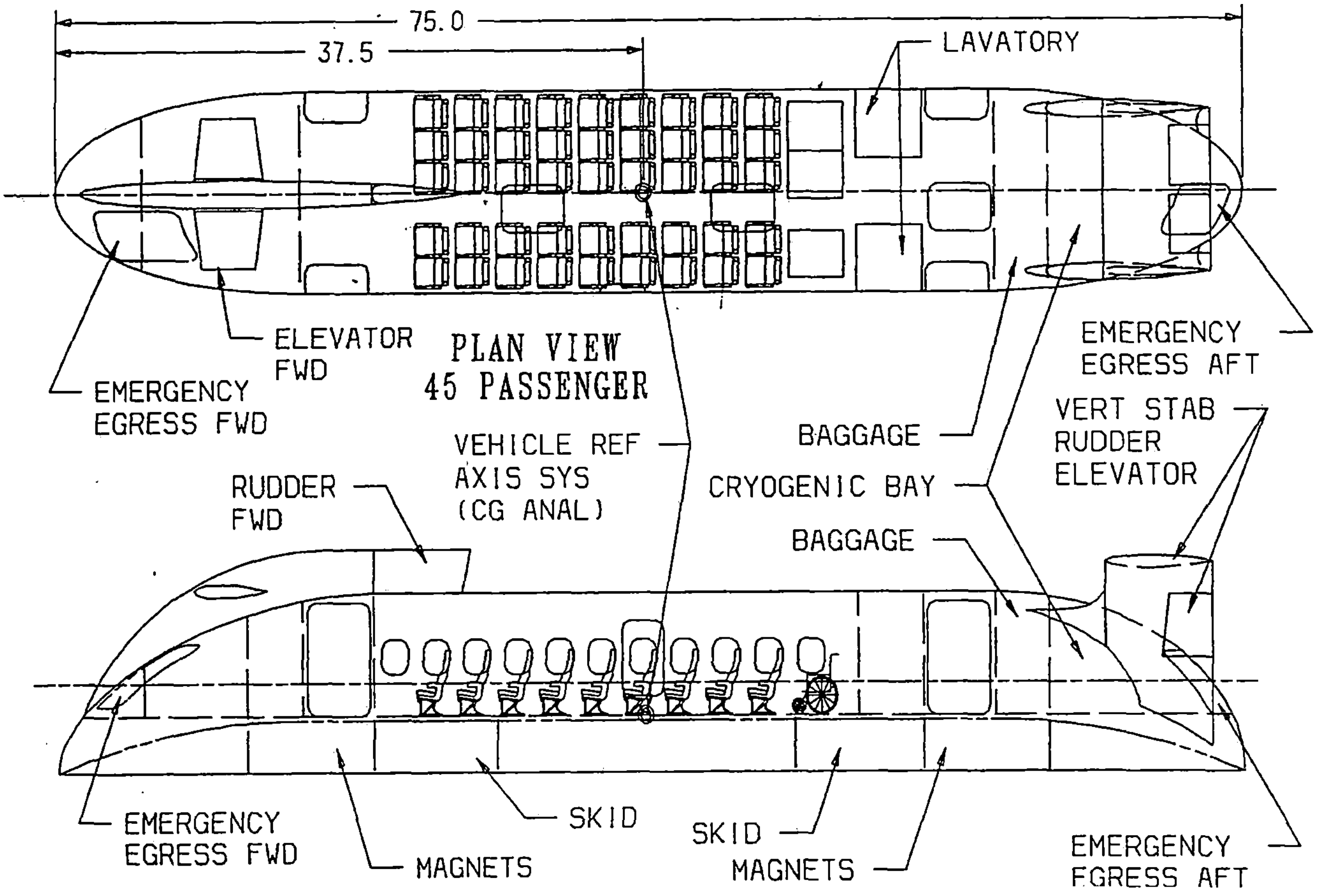

Figure 2 Plan and side views of 45-passenger magplane (measurements in feet)

or ride quality.

1.7. VEHICLE SWITCHING 3.2.2.d

Magplanes must enter and exit the main magway trunk at high speed, without slowing down the flow of traffic. A mechanical switch which requires bending a long section of magway was found to be too slow at minimum headways of twenty seconds to permit detecting a malfunction and taking corrective action. It was also found to be too sensitive to icing and too maintenance-intensive.

We have therefore invented and verified a magswitch without moving parts which can be actuated and confirmed in a fraction of a second, requires no power to operate, and is fail-safe in the event of power failure.

The magway trough widens to form a side-branch, and the vehicle is guided between the main trunk and the branch by selectively opening or short-circuiting two sets of passive coils by means of relays. These coils are the magnetic equivalent of the mechanical "frog" used in conventional railroad switches. They can be default-wired for the vehicle to either continue, or exit the magway in the event of power failure.

1.8. CAPACITY AND UPGRADE 3.2.3.j.

Two sizes of Magneplane vehicles: a 45-passenger and a 140-passenger vehicle have been designed. Small vehicles may be used initially. As part of an integrated upgrade plan, large vehicles (requiring more power) will be built later to provide higher capacity.

1.9. COOLING 3.2.1.a.2.

The Magneplane superconducting magnets require cooling to 8 degrees Kelvin. The Magneplane cryogenic refrigerator circulates coolant (supercritical helium, helium above its critical pressure where it cannot form bubbles) through the conduit which surrounds the superconducting wire. "Cable-in-conduit" magnets of this type were developed by our team and are used in most of the largest superconducting magnets world-wide. The technique eliminates the need for immersion in liquid helium. Magnets are surrounded only by a vacuum container and a nitrogen-cooled heat shield.

1.10. ON-BOARD POWER 3.2.1.j.

A high-frequency, backward-travelling wave superposed on the propulsion wave will induce about 200 kW of AC power in on-board pickup coils. It will be converted to standard line frequency and used to

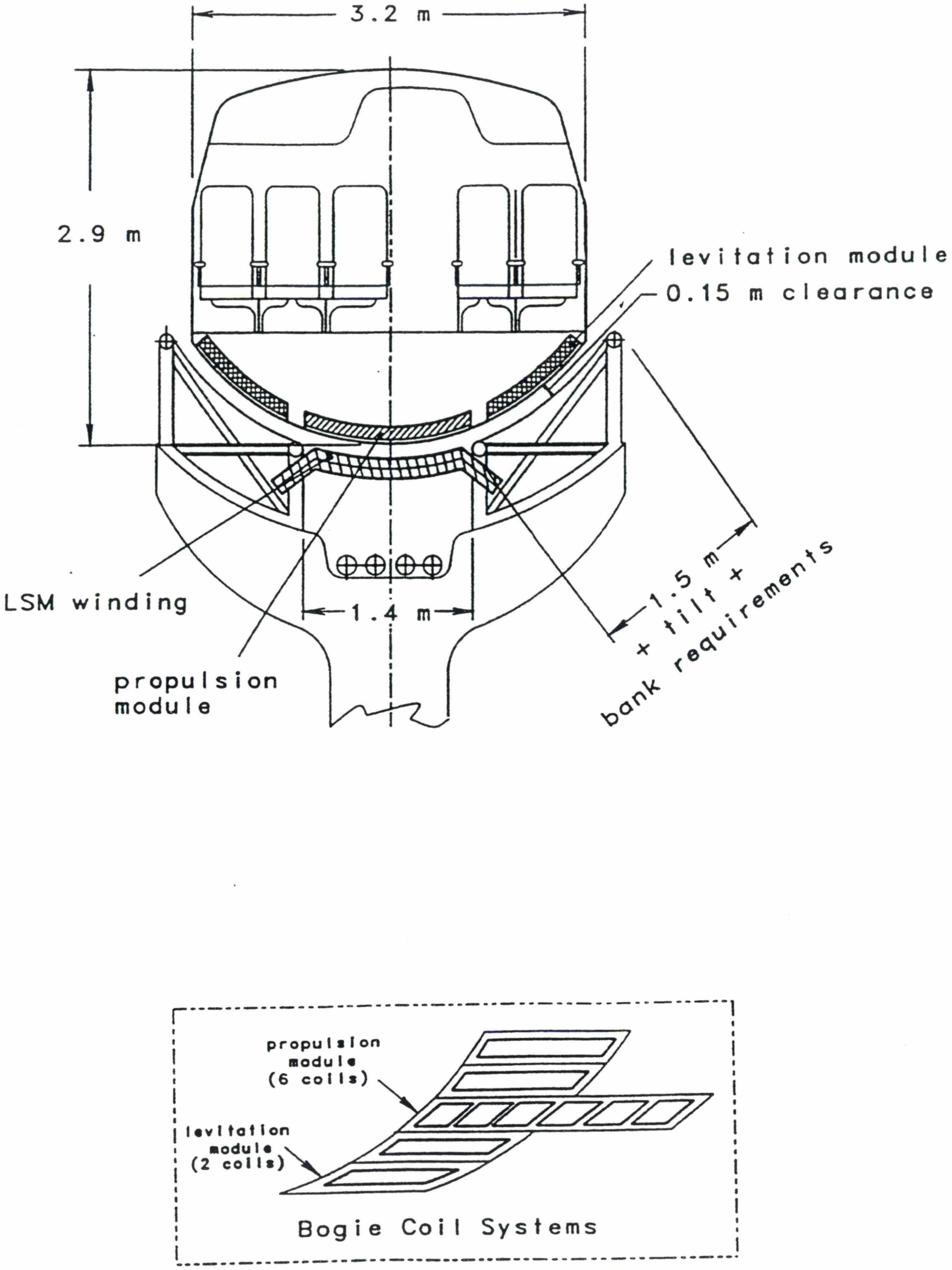

Figure 3 Vehicle cross-section and arrangement of bogie coil system (dimensions approximate)

power on-board actuators, lighting, heating and air conditioning equipment.

1.11. LANDING GEAR 3.2.1.d.

Magneplane's landing gear uses *air-lubricated pads* instead of wheels. These pads are lined with an anti-friction material and extended by actuators capable of lifting the vehicle to levitation height. A compressor forces air through holes in the bottom of these pads to generate an air cushion. This type of gear is desirable at landing speeds because it is more durable and dependable than wheels and requires less maintenance. It also facilitates station handling by permitting lateral motion and rotation on a flat surface.

1.12. EMERGENCY BRAKES 3.2.1.d.

Vehicle braking is normally done by the LSM, which can achieve more than 0.2 gee of acceleration or deceleration, converting about 80 percent of braking energy into useful power (regenerative braking). In case of LSM power failure, emergency brakes are used. High-friction skids are extended by actuators resembling the landing pads and produce up to 0.65 gee of emergency deceleration. Braking energy is dissipated in a length of magway which can absorb much more energy than a disk brake. Even the most advanced multi-disk, multi-caliper aircraft brakes of acceptable size would not suffice for a single emergency stop from 300 mph.

1.13. ACTIVE DAMPING 3.2.2.g.

Magnetically levitated vehicles of any type have no inherent damping mechanisms and will oscillate at their resonant frequencies. Magneplane vehicles exhibit slow oscillations (0.5 - 2 Hz) in all principal modes of motion (heave, pitch, yaw, sway, roll, and thrust). Vibrations at these frequencies are eliminated by an *active damping system.* Two mechanisms for damping are employed: the phase of the LSM is shifted to generate vertical forces which counteract vertical oscillations (heave), and aerodynamic surfaces oppose pitch, yaw and roll oscillations. This active system prevents oscillations before they start, unlike a passive shock-absorber which can only damp oscillations after they have developed.

1.14. CONTROLS 3.2.3.a.

Magneplane uses a multi-tiered self-inspecting fail-safe control system. There are three tiers of control hierarchy: *on-board, wayside* and *global.*

The **on-board control system** manages the landing gear, airfoils, emergency braking, door operating, and other vehicle-related functions. It monitors vehicle attitude, acceleration in all modes, and magway proximity. It calls the wayside power unit for appropriate correcting forces and moments to maintain ride quality by adjusting the phase and frequency of the LSM current and by actuating aerodynamic surfaces. Its input is a multi-sensor platform, and its output controls the wayside power conditioning units and the on-board control actuators for landing gear, brakes, doors, etc. The history of vehicle performance may be used to instruct subsequent vehicles about optimal ways to respond to magway conditions and to monitor the structural integrity of the magway.

A **wayside control system** in each magway block manages the LSM in that block. Its inputs come from the on-board control system, and from the Global control system. The wayside system also controls vehicle switching in any block that contains a magnetic vehicle switch.

The **global control system** manages the overall traffic on a continuous basis. It always maintains headways and speeds for all vehicles, plans routes so as to avoid bottlenecks, ensures optimum vehicle availability, and solves emerging traffic problems. It also responds to ticket purchases by scheduling vehicle destinations, and assigning passengers to vehicles. It receives input from the accounting/ticketing system at each station and each of the wayside control systems.

A **back-up** system relies on global positioning to ensure that vehicle position information is preserved in the event of power or communications failure.

1.15. TAKE-OFF AND LANDING MODES 3.2.3.i.

Induced repulsion will not suffice to lift the vehicle at speeds below about 18 m/s (40 mph), and available thrust will not suffice to reach take-off speed at zero gap. Drag is too high, and the magplane will not "get on the step. The landing gear must therefore lift the vehicle to levitation height and hold it there until take-off speed has been reached.

Lifted by air-lubricated landing pads, take-off will require only several hundred meters, or about half the length of a typical runway.

2. REPORT ORGANIZATION

The reports summarized in this executive summary are the

System Concept Definition Report (8 volumes)
Hypothetical Route Report (1 volume with set of drawings)
Concept Drawings (1 set of drawings)

These three items are deliverable 30 September 1992 under an 11-month System Concept Definition contract awarded by the US Department of Transportation under the National Maglev Initiative, and administered by the Army Corps of Engineers.

2.1. SYSTEM CONCEPT DEFINITION REPORT

Here is a list of the 30 sections that comprise the System Concept Definition Report. Sections numbers preceding some section titles correspond to the section numbers in the contract.

EXECUTIVE SUMMARY.

3.1. MAGLEV SYSTEM REQUIREMENTS: This section describes the design requirements as specified in the Statement of Work. (Volume 1)

MAGNEPLANE SYSTEM SPECIFICATIONS: This section contains a partial specification list in outline form of some principal areas of the system, including the baseline case for analysis. We used a 160 km straight route as the baseline case for costing and other analysis. (Volume 1)

GLOSSARY. (Volume 1)

INDEX: This is an index to all volumes. It appears in volumes 1 - 5.

3.2.1. SYSTEM DESCRIPTION - VEHICLE: This major section gives the preliminary design and description of the Magneplane vehicles - both the 45-passenger and the 140-passenger variant. (Volume 2)

3.2.2. SYSTEM DESCRIPTION - MAGWAY: This major section gives the preliminary design and description of the Magneplane magway and other fixed structures, including the magway electrical system and an analysis of vehicle/magway interactions. (Volume 2)

3.2.3. SYSTEM DESCRIPTION - SYSTEMWIDE: This major section contains a description of systemwide issues associated with the preliminary design, such as operations and maintenance, communication and control, power distribution, reliability, and capacity. (Volume 2)

5.3.2. TRADEOFF ANALYSES: This section contains description and analysis supporting the choice of major system components. (Volume 3)

5.3.3. PARAMETRIC PERFORMANCE REPORT: This section contains analysis to show the annual cost effect of variation of several important system parameters, such as velocity, passenger throughput, and power block length. Performance variables other than cost are also included. (Volume 4)

5.3.4. ENERGY ANALYSIS: This report examines the energy flow in the Magneplane system and provides discussion supporting energy use projections. (Volume 4)

5.3.5. MAINTENANCE PLAN: This report gives the costs of required maintenance for the system. (Volume 4)

5.3.6. MAGNETIC FIELD ANALYSIS: This report provides the detailed results of the analysis of ac and dc magnetic fields from each source, including interior and exterior fields, with cross sectional and longitudinal field maps. (Volume 4)

5.3.7. ADVANTAGES AND DISADVANTAGES: This report explains the advantages and disadvantages of the Magneplane system relative to other maglev concepts and other forms of transportation. (Volume 4)

5.3.8. PRELIMINARY ENVIRONMENTAL REPORT: This preliminary report explains the relevant environmental issues and gives estimates of the qualitative and quantitative impact of the Magneplane system on the natural environment. (Volume 5)

5.3.9. TEST AND DEVELOPMENT PLAN: This report describes Magneplane's plans for developing and testing a prototype system, and includes costs, schedules of work, and major items. (Volume 5)

5.3.10. SAFETY PLAN: This report addresses safety and safety planning in two parts: 1) the overall approach to safety, and 2) safety analyses conducted under this contract. (Volume 5)

5.3.11. LIFE CYCLE COST REPORT: This report contains preliminary cost estimates for each system component, the cost summary for the baseline route, and the resulting levelized annual costs in a number of forms. It also explains the analysis methods and gives a strategic plan for profitable operation. (Volume 5)

5.3.12. COST ESTIMATE FOR SYSTEM DEVELOPMENT: This report contains the specific financial and system development plans. Cost estimates as well as business strategies are included. (Volume 5)

5.3.13. EXTERNAL BENEFITS: This short report explains some of the major benefits of Magneplane development, such as technology spin-offs. (Volume 5)

RESPONSES TO C.O.E. COMMENTS: Over the course of the contract period, several sets of comments were received from the reviewers, which are reproduced in this section with our responses. (Volume 6)

SUPPLEMENT A: BACKUP MATERIALS FOR MAGWAY FOUNDATIONS: This section contains backup material from the foundation design process performed by Bromwell and Carrier, Inc. (Volume 6)

SUPPLEMENT B: BACKUP MATERIALS FOR COSTS: This section contains backup materials supporting the cost estimates as reported in section 5.3.11. (Volume 6)

SUPPLEMENT C: BACKUP MATERIALS FOR MAGWAY STRUCTURE: This section contains backup material from the magway civil structure design process performed by United Engineers and Constructors, Inc. (Volume 7A and 7B)

SUPPLEMENT D: VEHICLE SPECIFICATION: This section contains the detailed specification of the vehicle, prepared by Beech Aircraft Corporation. (Volume 8)

SUPPLEMENT E: LSM WINDING INDUCTANCE CALCULATION: This section contains backup material supporting LSM winding data reported in section 3.2., prepared by Failure Analysis Associates. (Volume 8)

SUPPLEMENT F: VEHICLE DYNAMIC RESPONSE EQUATIONS: This section contains backup material supporting the dynamic analysis results presented in section 3.2.2.g., prepared by MIT Lincoln Laboratory. (Volume 8)

SUPPLEMENT G: ROUTE ANALYSIS TOOLS: This section contains the software (printout) and usage notes for the route analysis tools, which were used by Magneplane International in the preparation of the Hypothetical Route Report and other reports. (Volume 8)

SUPPLEMENT H: HEAVE DAMPING CAPABILITY ANALYSIS: This section contains backup analysis supporting the capability of the LSM to damp heave oscillations, prepared by Failure Analysis Associates. (Volume 8)

SUPPLEMENT I: BACKUP MATERIAL FOR CONTROL & COMMUNICATION: This section contains backup material for all control and communication topics, to support the system described in section 3.2. (Volume 8)

2.2. HYPOTHETICAL ROUTE REPORT

The Hypothetical Route Report is the analysis of the Magneplane system applied to a route. Several route variations were studied: three variations of the Severe Segment Test (supplied by the customer) and a realistic route running from Tampa to Orlando, Florida.

Detailed results are given for power and energy usage, velocity, and curve specifications for the routes studied. The three variations of the Severe Segment Test correspond to three ride quality standards supplied by the customer. Drawings accompanying the report volume show the exact power and velocity profile over the route.

In addition to the analysis results, the report explains the route planning procedure which was used, and demonstrates that the route analysis results meet each required ride quality standard component.

The following drawings are included with the Hypothetical Route Report:

2.2.a. PLAN AND PROFILE OF SEVERE SEGMENT TEST (BEST RIDE QUALITY)

2.2.b. VELOCITY AND POWER PROFILES

2.2.c. MAGWAY AND VEHICLE DRAWINGS

2.2.d. ELECTRICAL DIAGRAMS

2.3. CONCEPT DRAWINGS

The concept drawings show the detailed preliminary design of vehicle and magway, plus a number of other components. The following drawings are included:

2.3.a. MAGWAY AND VEHICLE DRAWINGS

Vehicle/magway ISO	MAG 3
Magplane 140 - 3 view	
Magplane 140 - in-board profile	
Magplane 45 - 3 view	
Magplane 45 - in-board profile	
140-passenger vehicle	V-1
140-passenger vehicle and truss magway	GA-1
140-passenger vehicle and concrete magway	GA-2
Elevated magway pier systems	S-1
Levitation and propulsion elements	S-2
At-grade aluminum double magway straight section	S-5
Elevated aluminum double magway straight section	S-6
Aluminum double magway, 35° bank	S-7
Aluminum double magway, 24° bank	S-8
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Typical end-on construction	791001 A

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Major passenger terminal - Yard layout	MPT-1
Major passenger terminal - Loading level	MPT-2
Major passenger terminal - Passenger level	MPT-3
Major passenger terminal - Parking level	MPT-4

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Electrical distribution one line diagram - 4,000 passenger seats	E-1
Electrical distribution one line diagram - 8,000, 12,000 passenger seats	E-2
Electrical distribution one line diagram - 25,000 passenger seats	E-3
Converter station equipment arrangement	E-4

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Process flow diagram - cryogenic system	SH-1
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3.1. MAGLEV SYSTEM REQUIREMENTS

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3.1.1. SYSTEM REQUIREMENTS

The following list of system criteria includes those found in the contract and additions that we believe represent other crucial goals without which maglev could not be feasible. The additions are in section 3.1.4.

Each requirement includes a statement indicating if/how much the goal as been met as of the date of this preliminary report.

3.1.1.a. SPEED REQUIREMENT

Maximum cruising speed shall be 134 m/s, while trip averages shall be equal to or better than those achievable by commercial air systems for distances under 800 km (500 miles).

3.1.1.b. SYSTEM CAPACITY REQUIREMENT

Passenger capacity shall be at least 4,000 seats per hour per magway in one direction. A plan showing how each of the following capacities can be met shall be included:

Initial: 4,000
Upgrade: 8,000
Upgrade: 12,000
Upgrade: 25,000 - added by MI.

We add 25,000 because we believe that 12,000 may not be enough to effectively compete with other modes.

3.1.1.c. RIDE QUALITY REQUIREMENT

Four *ride quality standards* (complete sets of ride quality parameters) shall be used, detailed below.

- "BEST" (DESIGN GOAL - SOW) is the best standard from the passenger's perspective.
- "MIN-S" (MINIMUM REQUIREMENT - SOW) is the worst acceptable ride quality for standing passengers. Most routes should stay in the range between MIN-S and BEST.

	BEST (design goal)	**MIN-S (min. req.)**	**MIN-B (seated/ belted)**	**LAND**	**EMERG**
POSITION/ORIENTATION (deg)					
Max. Roll	24.00	30.00	45.00	45.00	45.00
SPEED/ORIENTATION (deg/s)					
Max. Roll	5.00	5.00	10.00	10.00	10.00
ACCELERATION/DISPLACEMENT (m/s^2, fraction of g)					
Max. Longitudinal	1.57, 016	1.96, 02	3.92, 0.4	5.88, 0.6	5.88, 0.6
Min. Up (with gravity)	9.74, 0.95	8.82, 0.9	8.82, 0.9	8.82, 0.9	7.00, 0,7
Max. Up (with gravity)	11.76, 1.2	12.74, 1.3	13.72, 1.4	13.72, 1.4	15, 1.5
Max. Lateral	0.98, 0.1	1.57, 0.16	1.96, 0.2	1.96, 0.2	3.00, 0.3
Max. Lat./long.	1.96, 0.2	2.94, 0.3	3.92, 0.4	5.88, 0.6	5.88, 0.6
Max. Lat./vert. (gravity excluded)	1.96, 0.2	2.94, 0.3	3.92, 0.4	3.92, 0.4	3.92, 0.4
Max. Total (gravity excluded)	2.35, 0.24	3.53, 0.36	3.92, 0.4	5.88, 0.6	5.88, 0.6
ACCELERATION/ORIENTATION (deg/s^2)					
Max. Roll	15	15	15	15	15
JERK/DISPLACEMENT (m/s^3): see notes					
Max. Lat.	0.69	2.45	2.45	2.45	4.00
Max. Vert.	0.98	2.94	2.94	2.94	4.00
Max. Long.	0.69	2.45	2.45	2.45	4.00
TEMPERATURE (C)					
Range in cabin	18-23	18-23	18-23	18-23	15-25
NOISE (dba)					
Max. in cabin	70	75	75	75	75
OSCILLATION: see notes					

Figure 1 Ride Quality Standards - Detailed

- "MIN-B" (SEATED/BELTED - SOW) is the worst acceptable ride quality for seated and belted passengers. MIN-B should only be used in selected sections of route where the number and radius of curves prevent adequate speed under the MIN-S standard.
- LAND is the worst acceptable ride quality for seated and belted passengers during take-off and landing. As in airplanes, an uncomfortable level of jerk and longitudinal acceleration is tolerated for a short time. (Note 1: if passengers are not seated and belted, MIN-S must be used for take-off and landing.) (Note 2: MI chose to use more comfortable standards instead of LAND for the Hypothetical Route Report.)
- "EMERG" is the worst acceptable ride quality for emergency conditions, in cases where partial control of ride quality still exists.

Figure 1 lists the ride quality details, organized by the ways of describing position, speed, acceleration, and jerk. Notes on the table are:

1. Jerk (m/sec^3) is filtered at 0.3 Hz, and measured peak-to-peak in 1 sec. For jerk oscillation guidelines, refer to SOW, Section C, Appendix A.
2. In MIN-B, all accelerations given in the contract as 5.88 m/s^2 (0.6 g) are reduced to 3.92 m/s^2 (0.4 g).

Magneplane can meet the BEST ride quality standard; however, reduction of ride quality will be traded against average velocity for the Hypothetical Route Report.

3.1.1.d. NOISE AND VIBRATION REQUIREMENTS

Noise and vibration transmitted from the system to the environment should be minimized and should be designed to meet existing Federal standards and industry practices, as appropriate.

3.1.1.e. MAGNETIC FIELD REQUIREMENT

Human exposure to magnetic fields should be safe and minimal.

3.1.1.e.1. MAGNETIC FIELD - VEHICLE

Magnetic fields in the vehicle originate from the magway LSM winding and from the on-board vehicle magnets. These fields are DC fields. Although the are no existing standards for continuous exposure to steady state (DC) magnetic fields, the earth's magnetic field level, about .5 gauss, is usually used for comparison. Magnetic fields and fields with shielding are compared to values specified in SOW, Section 3.2.1 (i).

3.1.1.e.2. MAGNETIC FIELD - MAGWAY

Magnetic fields produced by the magway is perceived as AC field at the propulsion frequency. Fields are compared to SOW, Section 3.2.1 (i) and standards adopted by New York. Comparisons are made to magnetic fields generated by utility transmission and distribution lines.

3.1.1.f. WEATHER OPERATION REQUIREMENT

The system should be the least affected by weather conditions in the area of operation, as compared with other modes. Operation compatible with all common U.S. weather conditions.

Magneplane withstands ice, snow buildup and temperature extremes; rain and humidity extremes; wind; and lightning. Optical visibility is not necessary for normal operation. (See Section 3.2.3.b).

3.1.1.g. CONTROL REQUIREMENT

Controls must be fully automated (no human operator in the loop) and fail-safe, and sensitive to information gained from system operation and meet requirements of SOW, Section 3.1.1.g..

Magneplane meets and exceeds this requirement (See Section 3.2.3.a).

3.1.1.h. SAFETY REQUIREMENT

The system must be safe, as indicated in the contract and detailed in our safety plan, Section 5.3.10.

3.1.1.i. MAGPORT (STATION) REQUIREMENT

Provision must be made for intermodal transfers. In addition, MI adds the requirements described in Section 3.1.4.b.

Magneplane meets this requirement (See Section 3.2.2.j).

3.1.1.j. AVAILABILITY AND RELIABILITY REQUIREMENTS

The system should have high availability, and be reliable and easy to maintain and inspect.

These requirements have not been fully specified.

3.1.1.k. AESTHETIC REQUIREMENT

The design should be aesthetically pleasing.

3.1.1.el. COMMUNICATIONS REQUIREMENT

The communications system should include provisions for non-vital communications. Magneplane meets this requirement (See Section 3.2.3.a).

3.1.1.m. HUMAN-FACTOR REQUIREMENT

Human factors should be evident in the design. (See Section 3.2.1.c).

3.1.2. VEHICLE REQUIREMENTS

3.1.2.a. VEHICLE CAPACITY/USE REQUIREMENT

Vehicles of different sizes and uses should be feasible with the same basic design.

Magneplane meets this requirement, although we have only designed passenger vehicles of two sizes in detail (See Sections 3.2.1.c and 5.3.2.1.c). Any vehicle type could be used, as long as it has the same external shape as our large vehicle, is not heavier, and has an equally low center of mass.

3.1.2.b. BRAKING REQUIREMENT

The system should have redundant braking capability.

Magneplane has natural braking through aerodynamic and magnetic drag, normal braking/power regeneration with the propulsion system, and emergency skid-brakes. Together they meet this requirement. (See Sections 3.2.1.b, d, and f).

3.1.2.c. VEHICLE STRUCTURAL INTEGRITY REQUIREMENT

Vehicles must withstand 2.5 m/sec impacts and have adequate fatigue-life. Magneplane meets this requirement (See Section 3.2.1.c).

3.1.2.d. ON-BOARD POWER REQUIREMENT

The vehicle must be equipped with emergency power adequate for emergencies, but should pick up normal operating power from the magway.

Magneplane has battery power which will sustain emergency conditions. The source of operating power is currently undecided between inductive pickup from the magway and an on-board auxiliary power unit (APU). An APU design is shown in Section 3.2.1.c. Work continues on an inductive power pick-up scheme and is described in Section 3.2.1.g. If the inductive pick-up design is successful, it will be presented in the final report.

3.1.2.e. EMERGENCY SYSTEMS REQUIREMENT

Vehicles must include adequate emergency systems. Emergency system requirements from the FAA are referenced in Section 3.2.1.c.

3.1.2.f. VEHICLE CONTROLS REQUIREMENT

Vehicles will include all necessary controls, including emergency manual controls and sensors to monitor magway conditions. Magneplane meets this requirement (See Sections 3.2.1.k and 3.2.3.a).

3.1.2.g. VEHICLE SANITARY FACILITIES REQUIREMENT

Vehicles must include sanitary facilities. Magneplane meets this requirement (See Section 3.2.1.c).

3.1.3. MAGWAY REQUIREMENTS

3.1.3.a. MAGWAY STRUCTURAL INTEGRITY REQUIREMENT

The magway shall have a minimum of a 50-year life.

Magway structure design has been optimized in this study for a 50-year life in seismic zone II and wind loads per ASCE 7-88. The magway can be readily modified for any seismic zone/wind speeds as dictated by local conditions. (See Sections 3.2.2.a and 3.2.3.b).

3.1.3.b. MAGWAY CONFIGURATION REQUIREMENT

Magways shall be bi-directional, allow cross-overs and turnouts, and have the capability to be constructed in tunnels, at grades or elevated. Magneplane meets this requirement (See Sections 3.2.2.a, d and k).

3.1.3.c. MAGWAY STRUCTURE REQUIREMENT

Magways should be adjustable and upgradable. Magway troughs should be of modular construction with an independent support structure.

The elevated Magneplane magway has an aluminum trough supported either by steel trusses or by concrete box beams that span between piers. (See Section 3.2.2.a).

3.1.3.d. VEHICLE ENTRY/EXIT REQUIREMENT

The magway should have switching capability. Magneplane meets this requirement. The present report contains a design for a mechanical switch (See Section 3.2.2.d), but designs for a passive switch are in progress. If those efforts succeed, the passive switch will replace the mechanical design.

3.1.3.e. MAGWAY CONTROLS REQUIREMENT

Controls should exist to monitor the magway and system operation. Magneplane meets this requirement (See Sections 3.3.3.a and g).

3.1.3.f. TUNNELS REQUIREMENT

Tunnels should not disrupt ride quality or safety. (See Sections 3.2.2.g and 3.2.2.k).

3.1.3.g. POWER SYSTEMS REQUIREMENT

Power systems should be adequate for 3.5% grade at full speed and 10% grade at reduced speed. Magneplane meets and exceeds this requirement (See Section 3.2.1.b).

3.1.3.h. BANKING REQUIREMENTS

Banked magways must be traversable at all speeds safely and emergency evacuation must be possible for vehicles stopped in curves. This topic is covered in Section 3.1.1.a. See Section 3.1.1.c for roll angle limits.

3.1.4. ADDITIONAL REQUIREMENTS

The following five requirements have been added by MI. Justification is given.

3.1.4.a. NEW CORRIDORS REQUIREMENT

It shall be possible to construct the magway along existing highway corridors. This requirement is crucial because it may not be economically feasible to build new corridors in areas where maglev systems are most needed. Magneplane meets this requirement by allowing steep banking (therefore high speeds) and curve radii compatible with highways.

3.1.4.b. TRIP TIME REQUIREMENT

Total trip time is composed of (1) maglev travel time, (2) connecting-mode travel time, (3) maglev waiting time, and (4) connecting-mode waiting time. Speed of maglev transit becomes less and less relevant as waiting times and/or travel times of connecting modes (subway, taxi, etc) increase.

The system shall operate such that the time a passenger typically has to wait for service is low (preferably much lower than trains or airplanes). Ideally average waiting time should be less than the interval at which scheduling in advance is necessary. Passengers should not have to plan around a schedule.

Maglev travel time depends on average velocity, which should be maximized. This can be done by having few or no intermediate stops, high acceleration, and/or high cruising speed.

Time spent waiting for and in transit on connecting modes depends on too many factors to formalize here. Nevertheless, it should be demonstrated that magports can be located in places where intermodal connections can or do exist, and that those connections can serve passengers in a timely way.

We estimate that Magneplane can meet these requirements in high-throughput urban areas, due to the use of single vehicles, which permit dynamic scheduling and small distributed magports. Waiting times may be greater in lower-throughput areas. No quantitative analysis has been done.

3.1.4.c. UPGRADE REQUIREMENT

It should be possible to increase capacity in planned stages while maintaining compatibility with older equipment. This requirement is necessary because ridership demands may change. Magneplane meets this requirement (See Section 5.3.2.1.c).

3.1.4.d. AUTOMOBILE COMPETITIVENESS REQUIREMENT

Evidence should be presented to show that the system will partially reduce the role of the automobile as the principal mode of transportation in the US. This requirement is absolutely crucial because it is the main reason for building a new form of transportation in the first place: to reduce the congestion, noise, pollution, and fatal accidents that are all caused by the automobile.

Magneplane meets this requirement by providing fast transportation between points where people are actually going at low waiting times and with few stops between. If it were not for these features, people would surely continue to drive their cars everywhere.

3.1.4.e. POWER DEMAND REQUIREMENT

Power demand should be minimized and be uniform over the whole system so that the voltage of the distribution system can be as low as possible.

Low and even power requirements are possible with Magneplane because vehicles are lightweight, small and evenly distributed.

3.1.5. STATEMENT OF WORK

The Statement of Work, section 1.0 is photocopied on the following pages.

SECTION C - DESCRIPTION/SPECIFICATION/STATEMENT OF WORK

MAGLEV SYSTEM CONCEPT DEFINITION
FEBRUARY 20, 1991

1.0 BACKGROUND

1.1 Preface

1.1.1 Magnetic levitation makes possible very high speed travel with the capacity and convenient access of rail. Despite these attributes and the availability of foreign developed technology, U.S. firms have declined to invest significantly in research and development for this new form of intercity transportation. Because magnetic levitation technology may represent a way to reduce congestion problems in the Nation's transportation corridors, the Federal Government has organized the National Maglev Initiative. It is the purpose of the Initiative to determine the extent to which Maglev is technically and economically viable in this country, and, if appropriate, to consider incentives for U.S. industry to develop and/or deploy the system.

1.1.2 At present, several major development efforts are underway in magnetic levitation for high-speed ground transportation. Examples include a German system (Transrapid) which has reached the prototype stage and is being considered for near term implementation in Florida on a 14-mile route from the Orlando airport to International Drive. A Japanese system has developed more slowly, with a final prototype system still 5-7 years off.

1.1.3 While other countries have developed highly successful high speed ground transportation, the United States continues to rely almost exclusively on the air and highway modes for intercity transportation. Increasing congestion on these modes results in ever worsening delays and escalating travel costs. It appears that more of the same may not be the solution to this problem. The cost and difficulty of acquiring the vast amount of land needed for airports and public opposition to the environmental impacts of both airplanes and highway vehicles makes a search for alternatives a prudent course of action.

1.1.4 There exist a great many ways that the technology can be assembled to produce a Maglev transportation system. What is needed is an embodiment that would make the system commercially successful in the U.S. environment. It is not clear that existing systems such as the German Transrapid and Japanese HSST or an emerging system such as Japan Railways' Linear Express satisfy U.S. requirements for commercial viability. The necessary traffic densities for success may require attributes not evident in these systems. These include trip times and costs competitive to air, and convenience and costs competitive to the private automobile.

1.1.5 Domestic air travel in the United States is much less expensive, distances greater, population densities lower, automobile ownership greater, urban transit poorer, and expectations greater, than is the case in Germany and Japan. Accommodating these differences requires innovative approaches to reduce costs and to provide superior service. Modifications which have been suggested include ways of providing service to intermediate points without slowing through traffic, making use of existing rights of way, such as railroads and Interstate highways, combining urban and intercity traffic on the same infrastructure, and facilitating transfer between complementary transportation modes (intermodality). Each of these aspects as well as any other pertinent issues need to be addressed to define benefits and costs so that informed judgments may be made. For example, use of existing rights of way may reduce land cost, but may impact operational speed adversely.

1.2 The National Maglev Initiative

1.2.1 Although the U.S. got an early start in magnetic levitation analysis and experiments, no major Federal research program has existed since the mid-seventies. Recently, there has been a resurgence of interest within the Federal Government.

1.2.2 As a part of the National Maglev Initiative, the U.S. Army Corps of Engineers and the Departments of Transportation and Energy have formulated a joint approach to assessing Maglev technology.

SECTION C - DESCRIPTION/SPECIFICATION/STATEMENT OF WORK
(Continued)

1.2.3 The ultimate objective is to evaluate the role of Maglev systems in the U.S. transportation system of the future. For purposes of this evaluation, it is assumed that a U.S. Maglev system could be available for implementation by the year 2000. The evaluation process is scheduled to be completed in 1992. A three phase program is planned.

Phase I - Planning and Coordination.

Phase II - Assessment of Technology, Economics and System Concept.

----- Decision Point -----

Phase III - Development and Implementation (subject to favorable result from the decision process)

1.2.4 The first procurement activity under the Initiative, a Broad Agency Announcement (BAA) for Technology Assessment, is intended to help industry get up to speed and to educate decision makers on the constituent technologies involved in Maglev and to discover the areas of risk and uncertainty and to try to reduce them.

1.2.5 Another part of Phase II is System Concept Definition which will ascertain industry approaches for putting together the constituent Maglev technologies into systems which are safe, environmentally acceptable, and attractive to investors. The complete spectrum of technological possibilities is of interest, from limited modifications of existing concepts to entirely new, different approaches. An important restriction on the possible spectrum of ideas, however, is that the technology proposed must currently exist or be available for application in the relatively near-term. In order to have a chance of competing with Maglev systems that have already reached the prototype stage, any new system should be available for implementation by the turn of the century. The concept must be defined and its soundness demonstrated by analysis within 12 months.

1.3 Subject of this procurement

1.3.1 This procurement addresses system concept definition, a portion of the Phase II efforts. Other work to be performed in Phase II includes technology assessment, issues of public-private partnership, market and economic assessments, development of safety standards and

SECTION C - DESCRIPTION/SPECIFICATION/STATEMENT OF WORK
(Continued)

environmental and health studies. The purpose of the other studies is to reduce the technological uncertainty and risk for the system developers, and to identify opportunities for making cost-effective improvements in Maglev technology, as well as to support the Government and industry decision process.

1.3.2 As a part of this requirement, the National Maglev Initiative solicits definition of Maglev system concepts from qualified firms. Requirements will include a system level conceptual definition and analysis effort resulting in a description of all the major subsystems and components of a Maglev transportation system, a description of how the subsystems interface with each other, an analysis of system performance including power requirements, speeds, capacity, acceleration, ride quality, noise, etc., and preliminary cost analysis including capital and operating costs as well as the time and cost of development to reach the prototype stage. The system must adhere to the system requirements furnished herein (paragraph 3.1). More detailed discussions of work requirements are contained in subsequent paragraphs of the scope of work.

1.3.3 The successful offeror(s) will be required to define candidate Maglev systems in sufficient detail that a preliminary evaluation of their performances and costs can be conducted. It is not the intent of this procurement to select a system for further development, but rather to generate information needed to determine the best approach to development of U.S. Maglev systems, the appropriate role of Maglev in the nation's transportation system of the future, and to evaluate whether Government support should be used to develop and implement Maglev technology.

1.3.4 The Government will evaluate the results from this system definition effort along with the outputs from the technology assessments, environmental and health, safety and economic/ market analyses and the institutional issues studies to form the basis for Government recommendations and decisions in 1992 concerning the future directions of the National Maglev Initiative. Future Maglev procurement activities, if any, will be the subject of a separate competition and will not be a continuation of this procurement.

SECTION C - DESCRIPTION/SPECIFICATION/STATEMENT OF WORK
(Continued)

2.0 SYSTEM CONCEPT OBJECTIVE

2.1 The National Maglev Initiative will evaluate system concepts with the objective of achieving an improvement in the performance capability of Maglev systems based on current and advanced Maglev technology and assessing the feasibility of developing a U.S. Maglev system that will be the system of choice in the U.S. and throughout the world. Existing foreign technology may be used as a basis for proposing and developing an advanced U.S. System. In response to the Initiative, the concepts that will be defined under this contract will be required to incorporate all relevant aspects of a commercial Maglev system, including the vehicle, the infrastructure (guideway and stations), suspension, guidance, propulsion, braking, safety, power distribution and control and communication systems. This system concept definition effort will provide information on the capabilities of Maglev systems and will help define what efforts are needed to turn the conceptual systems into reality.

2.2 In soliciting the system concepts, the National Maglev Initiative views Maglev as an intercity transportation system which will supplement and interconnect with existing modes. Specific attention should be given in defining the system concept for the need to have effective intermodal connections for transfer of passengers and baggage to their final destinations via other modes of transportation. Maglev systems should be safe and reliable. In the 160 km-1 Mm (100-600 mile) trip range, Maglev should be competitive in terms of travel times, cost, reliability and comfort.

2.3 It should be clean and energy efficient. It should provide good connections with airports and major centers. Insofar as possible, it should utilize existing highway, railroad, and utility rights-of-way. Its design should anticipate upgrade. It should be economically and financially attractive. It should be robust in terms of its susceptibility to adverse weather and its requirements for maintenance. It should efficiently handle passengers and consideration should be given to its mail and freight handling capability.

2.4 In 1992, the National Maglev Initiative will reach a major decision point. The evaluation of the system concepts that will be defined under this contract will provide a major contribution to determining the future course of the Initiative. It must be emphasized that Maglev is a candidate for intercity transportation of the future. To be successful it must be superior to the alternative technologies of the year 2000 and beyond, including improved high speed rail, improved air and any new foreseeable technologies.

SECTION C - DESCRIPTION/SPECIFICATION/STATEMENT OF WORK
(Continued)

3.0 REQUIREMENTS

3.1 Maglev System Criteria

System concepts shall meet the criteria as listed below. These criteria were developed by consensus among the industry, academic and government participants in the July 1990 Maglev Workshop conducted at the Argonne National Laboratory. Those criteria statements which are preceded by MR (minimum requirements) are performance specifications which a proposed system must meet to be acceptable. Those which are preceded by DG (design goals) are target performance levels and are considered important, but will not be essential conditions of acceptability for proposed systems.

3.1.1 System Requirements

(a) Speed - (DG) Cruising speed of 134 m/s (300 mph) or more. The cruising speed for a particular system is the result of tradeoffs of route alignment, power supply capacity, passenger throughput, along with other parameters. The Maglev system speed should be sufficient to allow total trip times equal to or better than those achieved by current commercial air systems.

(b) Capacity - (DG) Capacity should be in the range of 4,000 to 12,000 passenger seats per hour in each direction. The lower figure would be appropriate with a guideway of low cost. The higher figure would appear to be required to serve the very highest volume markets, possibly with some increase in capital cost.

~~(c) Ride Comfort - (DG) the system shall provide a level of ride comfort equivalent to computed levels using the "composite" method described in "Development of Techniques and Data for Evaluating Ride Quality, Vol. II, Feb., 1978, Report # DOT-TSC-RSPD-77-1, II, R.D. Peplar et al." The composite method is derived from analysis of both airplane and ground system environments and considers linear accelerations of the vehicle (primarily transverse and vertical), angular rotation of the vehicle (primarily roll rate) and the acoustic noise levels. Appendix A provides additional detail.~~

SEE
CONTRACT
APPENDIX
B.

(d) Noise and Vibration - (DG) The noise and vibration produced by total system operation should be designed to meet existing Federal standards and industry practices, as appropriate, for stationary facilities such as maintenance areas and stations. Noise and vibration produced by the vehicle traversing the guideway should be minimized. Potential noise and vibration impacts and possible mitigation methods in urban areas should be given special attention. The Code of Federal Regulations, Title 40, Chapter I, part 201, Noise Emission Standards for Transportation Equipment; Interstate Rail Carriers should be used for guidance but caution must be used in extrapolating such information to high speed operations at or near grade.

(e) Magnetic Fields - (DG) Human exposure to steady and fluctuating magnetic fields shall be minimized and consider current research findings.

(f) Weather - (DG) Operation compatible with all common U.S. weather conditions (e.g., wind, snow, rain, fog, icing, heat, lightning, etc.) with minimal degradation in system performance. In the region of operation, Maglev should be the transportation mode least affected by adverse weather conditions.

(g) Controls - (MR) All controls must be fully automated and fail-safe. (DG) A central facility will operate the system, receiving and integrating data regarding the status and integrity of all vehicles and guideways, the locations of all vehicles, guideway power requirements, vehicle routing requests, etc. (MR) The system control software must also be fail-safe, equivalent to the level of reliability defined by the Federal Aviation Administration (FAA) for flight control software for military and civilian aircraft. See Federal Aviation Regulation 25.1309, Amendment 25-23 and Advisory Circular 25.1309-1. Copies of the referenced material will be made available, upon request, to the offerors.

(h) Safety - (MR) A system safety plan must be included which discusses possible failure modes, human operation considerations, evacuation procedures, system restart, equipment and software availability, safety inspections, consequences of vandalism and trespassing, etc. The central control facility will log all operations and communications for subsequent analysis in the event of a failure. Consideration must be given to safe use of materials and construction methods, and to the safety of other users of the rights-of-way.

(i) Station Operation - (DG) Provision should be made for convenient and efficient inter- and intra-modal transfer and transport of passengers, baggage and freight.

(j) Availability and Reliability - (DG) The design should have high system availability and subsystem reliability, maintainability and ease of inspection.

(k) Aesthetics - (DG) Attention to aesthetics should be evidenced in the design to increase public acceptance and ensure consideration of economic aspects.

(l) Communications - (DG) The system will include provisions for non-vital voice, data, and video communication capability.

(m) Human Factors (DG) Human factors considerations, including the operator, passengers and maintenance considerations shall be evidenced in the design.

3.1.2 Vehicle Requirements

(a) Capacity - (DG) Vehicles of different sizes, configured to carry passengers and/or freight, should be feasible with the same basic design.

(b) Braking System - (MR) Vehicles must have redundant braking systems which are fail-safe. Normal braking of up to 0.2g should be considered.

(c) Structural Integrity - (MR) Vehicles must safely withstand high-speed impacts with small objects such as birds, debris, snow and ice. Vehicles must also have adequate fatigue life and low-speed crash worthiness and shall sustain only minimum damage in a 2.2 m/s (5 mph) impact.

(d) On-Board Power - (DG) All power for normal hotel functions, controls, levitation, etc. should be transferred from the guideway. (MR) The Vehicle must be equipped with emergency power for operation, as appropriate within the system safety plan.

(e) Emergency Systems - (MR) Vehicles must include emergency systems for fire fighting, lighting, HVAC, evacuation, communication, etc. as appropriate within the system safety plan.

SECTION C - DESCRIPTION/SPECIFICATION/STATEMENT OF WORK
(Continued)

(f) Instrumentation and Controls - (MR) The system shall include instruments which monitor the integrity of the guideway (presence of debris, snow and ice, misalignment or deterioration of guideway, etc.) and the status of on-board systems (propulsion, levitation, guidance, power, safety, etc.). Data acquired should be recorded and fully integrated into vehicle and overall-system controls to allow appropriate response in emergency and normal operations. In normal operation, vehicles will be monitored or controlled from a central facility. However, vehicles will include manual controls for emergency and maintenance operations.

(g) Sanitary Facilities - (MR) Space must be provided for sanitary facilities, including a retention system.

3.1.3 Guideway Requirements

(a) Structural Integrity - (MR) Civil structure (foundation and structure supporting the guideway) shall have a minimum 50-year life. Consideration shall be given to structural integrity under earthquake and high-wind conditions.

(b) Configuration - (DG) Guideways will normally be elevated and have bi-directional capability but must also accommodate near grade and underground applications. Single guideways must include provision for passing vehicles and future expansion. Dual guideways must include crossovers to sustain partial service during routine maintenance and repair of local failures. The central facility will control crossovers and bi-directional traffic.

(c) Structure - (DG) To facilitate maintenance, repair of local failures, and eventual system upgrade, guideways should be of modular construction with an independent support structure. This support structure (foundations, piers, beams, connectors) should be designed to accommodate growth in traffic (see System Capacity). The design should also include means for vertical and lateral adjustment of guiding elements to maintain required tolerances.

(d) Vehicle Entry/Exit - (DG) Entry/exit to off-line stations, feeder lines and other main lines should minimize vehicle headway requirements and overall trip time.

(e) Instrumentation and Controls - (MR) The system shall include instruments which monitor guideway integrity (presence of debris, snow and ice, misalignment or deterioration of guideway, etc.), the status of its subsystems (propulsion, levitation, guidance, power, entries/exits, etc.) and the locations and velocities of all vehicles. Data acquired should be fully integrated into guideway and overall-system controls to allow response in both emergency and normal operations.

(f) Tunnels - (MR) Design of tunnels shall address issues of comfort, noise and safety, with special attention to vehicle entry and passing vehicles.

(g) Power Systems - (DG) Power systems should be sized to provide vehicle acceleration and braking capacity for all operating conditions and should be capable of meeting requirements for system capacity. Guideway power systems should be capable of sustaining vehicles at full cruising speed up sustained grades of 3.5:100, and provide vehicle propulsion at reduced speeds up a maximum grade of 10:100.

(h) Superelevation - (MR) Superelevated (banked) guideways must provide for safe operation of vehicles at all speeds from zero to the maximum design speed of the curve. Emergency evacuation must be possible from vehicles stopped in a curve.

MAGNEPLANE SYSTEM SPECIFICATIONS

This outline includes major specifications that affect subsystem interfaces and all operations, but does not include detailed subsystem specifications.

I. vehicle structure and properties
  A. small vehicle size
    1. length: 22.9 m
    2. bogie separation (levitation coil center to center): 13.0 m
    3. capacity: 45
    4. mass: 25,000 kg
  B. large vehicle size
    1. length: 38.4 m
    2. bogie separation (levitation coil center to center): 28.6 m
    3. capacity: 140
    4. mass: 47,700 kg
  C. cross sectional dimensions
    1. width: 3.5 m
    2. height: 2.9 m
    3. radius of underside: 1.95 m
    4. underside to CG (center of gravity) distance: 1.1 m
    5. underside to CL (center of lift) distance: 1.95 m
    6. walkway height: 1.9 m
    7. floor to underside distance: 0.91 m
    8. seats abreast: 5
  D. other specifications
    1. doors
      a. normal use: four, two on each side
      b. emergency: two: one on each end
      c. total: six
  E. aerodynamics
    1. aerodynamic drag (coefficient of v^2)
      a. small vehicle: 0.85 Ns^2/m^2
      b. large vehicle: 1.07 Ns^2/m^2
  F. landing gear
    1. coefficient of friction: 0.05
    2. deployment time: 6.5 s
    3. area: 7 m^2
    4. placement: 4 pads, 1 at each corner
  G. emergency brakes
    1. coefficient of friction: 0.65 (max)

    2. deceleration capabili~~b~~ty: 0-4.9 m/s^2
    3. deployment time (0-75% lift): 3.5 s
    4. area: 3.5 m^2
    5. placement: 4 pads, 1 at each corner

H. on-board superconducting magnets
    1. temperature: 8 K
    2. material: Nb_3Sn (niobium-tin)
    3. form: 5 mm square cable in conduit (CIC)
    4. levitation coils configuration
        a. suspension: 2 points (bogies)
        b. number of modules per bogie: 2
        c. number of coils per module: 2
        d. total lift modules: 4 (one on each corner)
        e. total number of coils: 8, all independent cryostats
    5. propulsion coils configuration
        a. number of modules per bogie: 1
        b. number of coils per module: 6
        c. total number of coils: 12 in 2 independent cryostats

I. on-board power
    1. total demand
        a. normal operation: 185 kW
        b. reduced performance 1: 79 kW
        c. reduced performance 2: 59 kW
        d. reduced performance 3: 12 kW
    2. battery capacity: 119 MJ
    3. battery life without charging
        a. reduced performance 1: 1500 s (25 min)
        b. reduced performance 2: 2040 s (34 min)
        c. reduced performance 3: 9900 s (165 min)

II. magway structure and properties

A. spans, nominal
    1. type: aluminum box beam
    2. length: 9.1 m between supports
    3. deflection tolerance (full scale): 0.0046 m
    4. materials options
        a. reinforced concrete
        b. steel truss

B. trough
    1. radius of cross-section: 2.1 m
    2. radius of horizontal curvature
        a. normal operation: 600+ m   not 400! Can vehicle negotiate?
        b. operation on landing gear: no limits
    3. average angle of levitation plates: 36 degrees from horizontal
    4. bank angle: 0-35 degrees
    5. levitation plate
        a. thickness: 0.02 m
        b. width: 1.6 m

- C. magway-based linear synchronous motor (LSM)
  - 1. blocks
    - a. each block is a separate motor winding
    - b. block length: variable, up to 2 km
    - c. restrictions: only one vehicle on a block for normal operation
  - 2. windings
    - a. 3 phases
    - b. current: 0-3225 A
    - c. wavelength: 1.5 m
    - d. winding width: 1.2 m (varies in some regions)
    - e. pole pitch 0.75 m
    - f. resistance
      - (1) normal windings: 0.1 Ω/km/phase
      - (2) low-resistance winding: 0.05 Ω/km/phase
    - g. configuration: biplanar, lap-wound aluminum litz cable
  - 3. converter
    - a. ratings: 6, 12, 18, 24 MW
    - b. one converter per block
  - 4. efficiency
    - a. LSM
      - (1) 2 km with 8.2 MW input power: 91.5%
      - (2) other configurations: efficiency varies
    - b. converter: 95.0%
    - c. substation and other losses: 2.0%
    - d. approximate total without acceleration: 85%

- III. power distribution
  - A. substations
    - 1. spacing: 8 block lengths
    - 2. supplies 34 kV bus
  - B. bus
    - 1. dual
    - 2. length: entire corridor
    - 3. voltage: 34 kV
  - C. converter station
    - 1. fed by 34 kV bus
    - 2. converters per station: 4
    - 3. converter station spacing: 2 or 4 block lengths
  - D. upgrades
    - 1. number and spacing of equipment depends on specific upgrade plan
- IV. magway-vehicle interactions
  - A. separations at cruising speed
    - 1. between vehicle skin and magway surface: 0.15 m
    - 2. between levitation coil center and magway surface: 0.20 m
    - 3. between propulsion coil center and LSM winding center: 0.25 m
  - B. separations at zero speed on flat magway (on landing gear)
    - 1. between vehicle skin at landing gear centerline and magway surface: 0.40 m (vertical)

        2. between propulsion coil center and LSM winding center: 0.25 m
    C. total load on levitation plates (no curves)
        1. large vehicle: 605055 N
        2. small vehicle: 302528 N
    D. velocity
        1. design range: 0-150 m/s
        2. curved magway operating range: 0-134 m/s
        3. flat magway operating range: 0-30 m/s
        4. range of transition to full magnetic lift and curved magway: 30-50 m/s
    E. accelerations
        1. normally limited by ride quality and power, up to 0.4g
        2. max emergency deceleration: 4.9 m/s^2
    F. roll: ±3 degrees from magway bank angle
    G. headway
        1. depends on
            a. max emergency deceleration: 4.9 m/s^2
            b. total reaction/brake deployment time: 4 s
            c. min clear headway after complete stop: 300 m
        2. headway required for safety at 134 m/s: 20 s

V. communications and controls
    A. control levels
        1. vehicle
            a. controls: vehicle
            b. communicates with wayside and global
            c. responsible for: fine position/velocity control, magway monitoring, active stabilization
        2. wayside
            a. controls: vehicles in block
            b. communicates with vehicle and global
            c. spacing: 1 per block
            d. responsible for: LSM control, active stabilization, magswitch control
        3. global
            a. controls: corridor
            b. communicates with vehicle and wayside
            c. spacing: 1 per 160 km
            d. responsible for: scheduling, routing, emergency responses
    B. scheduling method: dynamic, responsive to current demand
    C. routing method: dynamic, responsive to current conditions
    D. active stabilization method: LSM modulation and aerodynamic control surfaces
    E. emergency operations
        1. methods: responsive to failure and current conditions
        2. level of control: all levels

VI. human factors
    A. ride quality: as per government specs
    B. magnetic field exposure: as per government specs

VII. performace summary
    A. minimum radius for coordinated curves (zero lateral acceleration)

1. 134 m/s, 24° roll: 4115 m
2. 134 m/s, 30° roll: 3173 m
3. 134 m/s, 45° roll: 1832 m
4. 100 m/s, 24° roll: 2292 m
5. 100 m/s, 30° roll: 1767 m
6. 100 m/s, 45° roll: 1020 m
7. 60 m/s, 24° roll: 824 m
8. 60 m/s, 30° roll: 640 m

B. total drag
   1. small vehicle at 150 m/s: 26.640 N
   2. large vehicle at 150 m/s: 39,150 N
   3. small vehicle on landing gear at low speed: 15,130 N
   4. large vehicle on landing gear at low speed: 30,250 N

C. operating headway
   1. all large vehicles at 4,000 pas/hr: 126 s
   2. all large vehicles at 12,000 pas/hr: 42 s
   3. all large vehicles at 25,000 pas/hr: 20 s

The following specifications are given for the study of various system parameters. Since many of the construction and operational elements for the system are route and capacity specific, it is necessary to use a standard configuration so that study variables are considered in a uniform framework. That is, the parameters below are not "fixed" by the system concept; they are arbitrarily chosen for uniformity of analysis.

The configuration specified below is used to study costs, reliability, safety, energy usage, and a number of other parameters as detailed in the Parametric Performance Report. Separate parameters are used in the Hypothetical Route Report, as required by the contract.

System elements placed on an actual route may have different optimization values than those outlined below and will certainly have different costs. In particular, the number of magplanes and magports cannot be decided in advance, so these elements are costed separately. Also during the development of a real system it would not be anticipated that all vehicles would be 140 passenger vehicles or that they would all be built in advance. System operation would start with a low number of vehicles and be augmented as required. Thus the development costs of a new system would not include the cost of an entire fleet prior to operation.

VIII. specific configurations for uniformity of analysis

A. straight magway configuration **(STR)**
   1. magway structure
      a. dual (two directions)
      b. height: 5.2 m
      c. span length: 9.1 m
      d. material: all aluminum
   2. ancillary structures
      a. switches: none
      b. magports: none

    3. route
        a. straight and level, all elevated
        b. length: 160 km
    4. blocks
        a. block size: 2 km
        b. number of blocks in system: 160
        c. power converter station spacing: 8 km
        d. number of power converter stations: 20
        e. converter rating: 6 MW
        f. converters per station: 4
        g. number of converters in system: 80
    5. power substations
        a. separation: 53 km
        b. rating: 60 MVA
        c. number of substations in system: 3
    6. control
        a. global controllers: 1
        b. wayside controllers: 20
B. realistic to severe magway configuration (SEV)
    1. magway structure: see primary configuration
    2. ancillary structures: see primary configuration
    3. route
        a. first half of Severe Segment Test (see Hypothetical Route Report)
        b. length: 400 km
    4. blocks: variable
    5. power substations: variable
    6. control
        a. global controllers: 3
        b. wayside controllers: variable
C. operating time
    1. per day: 18 hr
    2. per year: 6570 hr
    3. system life: 50 years (328,500 hr)
D. service and routes for various types of analyses
    1. for reliability/safety studies
        a. route: STR
        b. ride quality: BEST
        c. vehicles
            (1) relating to passenger safety: 1 large (140-passenger)
            (2) relating to system safety: 20 large (140-passenger)
        d. throughput: N/A
        e. velocity: 134 m/s
    2. for economic tradeoffs and parametric studies
        a. route: depends on the study
        b. ride quality
            (1) BEST when using STR
            (2) MIN-B when using SEV

- c. vehicle mix: all large (140-passenger)
- d. throughput
    - (1) 4,000 pas/hr = 1.11 pas/s
    - (2) time between vehicles (headway): 126 s
    - (3) lifetime throughput: 1.314×10^9 passengers
- e. velocity, when not otherwise calculated: 134 m/s

3. for costing
    - a. route: STR
    - b. ride quality: BEST
    - c. vehicles: 20 large (140 passenger)
    - d. throughput
        - (1) 4,000 pas/hr = 1.11 pas/s
        - (2) time between vehicles (headway): 126 s
    - e. velocity: 134 m/s

GLOSSARY

of abbreviations and some terms used in this report

A-PADS. Anti-friction pads used in the landing gear

ATTENDANT. Person who travels on a vehicle to aid passengers; specifically *not* a driver

BAC. Beech Aircraft Corporation, subcontractor

BANK. The angle at which the LSM winding centerline is offset from the bottom of the magway trough

BCI. Bromwell & Carrier, Inc., subcontractor

BLOCK. A portion of magway containing one electrically isolated LSM winding

BOGIE. Set of lift and propulsion magnets; the point of lift in the vehicle

CAPACITY. The maximum throughput, eg. passengers per hour.

CHANDELLE. A maneuver that offsets the unwanted upward force from going over the crest of a hill with downward force generated from a horizontal curve

CLEARANCE. Distance between outside surface of vehicle and top surface of magway (see figure)

COORDINATED CURVES. (or coordinated banking) Curves that are negotiated in such a way that passengers feel no lateral (sideways) forces, other than roll acceleration

CRS. Cryogenic refrigeration system

CRYO-. (cryogenics, cryostat) Prefix denoting refrigeration

DYNAMIC SCHEDULING. The method of planning vehicle routes based on instantaneous need (ticket purchases)

EFFECTOR. An element of control, including the sensors, control logic, actuators, and the whole response pathway

FAA. Failure Analysis Associates, subcontractor (also Federal Aviation Administration)

FORK. The operation of a vehicle going through a switch approaching from the one-troughed end

GAP. (or LSM gap) Distance between LSM winding center and propulsion magnet center (see figure)

H-PADS. High-friction pads used in the emergency brakes

HEADWAY. The amount of clear time or distance in front of a vehicle

HEIGHT. Distance from levitation magnet center to surface of magway

KEEL EFFECT. The tendency of the LSM operation to exert a righting moment to stabalize the vehicle (A boat's keel stabalizes the boat although it does not exert a righting moment)

LANDING GEAR. Apparatus to levitate magplanes in the absence of magnetic levitation

LEVITATION SHEETS. Sheets of aluminum on both sides of the magway trough

LL. Lincoln Labs (MIT), subcontractor)

LNG. Liquid natural gas

LSM. Linear synchronous motor

LSM GAP. Distance between LSM winding center and propulsion magnet center (see figure)

MAGLEV. The field of study concerned with magnetic levitation; also the maglev mode of transportation

MAGNEPLANE. The short name for Magneplane International, Inc

MAGPLANE. Maglev vehicle

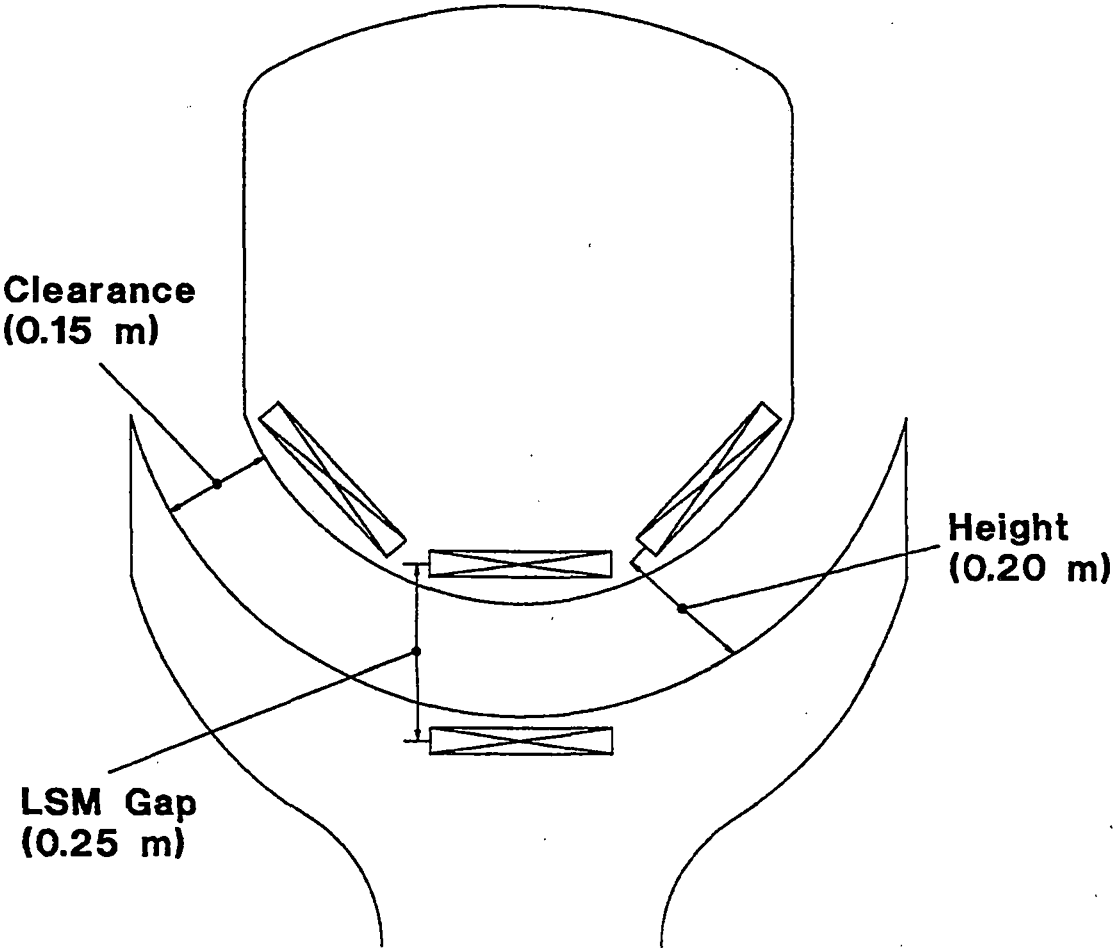
MAGPORT. Passenger access point to a maglev system

MAGWAY. Track, or guideway for a magplane

MAGWAY TROUGH. The part of the entire guideway support structure on which the vehicle runs, and which contains the LSM and levitation sheets

MEANDER WINDING. The type of conducting coil used in the LSM

MERGE. The operation of a vehicle going through a switch approaching from the two-troughed end
MI. Magneplane International
MIT. Massachusetts Institute of Technology, subcontractor
MTBF. Mean time between failures
MTTR. Mean time to repair
PFC. MIT Plasma Fusion Center, subcontractor
PFD. Process flow diagram
PSI. Process Systems International, subcontractor
RED. Raytheon Equipment Division, subcontractor
ROLL ANGLE. The angle of roll of a vehicle in a curve, where zero is vertical
SKIDS. The external surfaces of both the landing gear (A-pads) and the emergency brakes (H-pads)
SLOT. A position in the traffic stream that can be occupied by a vehicle, or left open for a vehicle entering the stream; Not to be confused with "block"
SPAN. Distance from magway pier to pier; also the section of magway within that span
SWITCH. The portion of magway on which one trough connects to two
TBD. To be determined
THROUGHPUT. A measure of the activity of a maglev system, typically in passengers per hour
UEC. United Engineers and Constructors, subcontractor



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