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MAGNETIC LEVITATION SYSTEMS FOR FUTURE AERONAUTICS AND SPACE RESEARCH AND MISSIONS

Presentation at Workshop

TRANSPORTATION BEYOND 2000:
TECHNOLOGIES NEEDED FOR ENGINEERING DESIGN
NASA Langley Research Center
Hampton, VA

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MAGNETIC LEVITATION SYSTEMS FOR FUTURE AERONAUTICS AND SPACE RESEARCH AND MISSIONS

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Washington, D.C.

ABSTRACT

The objectives, advantages, and research needs for several applications of superconducting magnetic levitation to aerodynamics research, testing, and space-launch are discussed. Applications include very large-scale magnetic balance and suspension systems for high alpha testing, support interference-free testing of slender hypersonic propulsion/airframe integrated vehicles, and hypersonic maglev. Current practice and concepts are outlined as part of a unified effort in high magnetic fields R&D within NASA. Recent advances in the design and construction of the proposed ground-based Holloman test track (rocket sled) that uses magnetic levitation are presented. It is projected that ground speeds of up to Mach 8 to 11 at sea-level are possible with such a system. This capability may enable supersonic combustor tests as well as ramjet-to-scramjet transition simulation to be performed in clean air. Finally a novel space launch concept (Maglifter) which uses magnetic levitation and propulsion for a re-usable "first stage" and rocket or air-breathing combined -cycle propulsion for its second stage is discussed in detail. Performance of this concept is compared with conventional advanced launch systems and a preliminary concept for a subscale system demonstration is presented.

OUTLINE OF PRESENTATION

- MAGNETIC LEVITATION R & D AT NASA
  - Rationale for infrastructure building

- APPLICATIONS OF MAGNETIC LEVITATION
  - MSBS
  - HOLLOMAN AFB TEST TRACK UPGRADE
  - MAGLIFTER / LUNATRON

- MASS TRANSPORTATION - - "MAGLEV"
  (airplanes flying in extreme ground effect)
  - TECHNOLOGY NEEDS
  - RECENT DEVELOPMENTS IN JAPAN

超電導リニアモーターカー・マグレブの原理

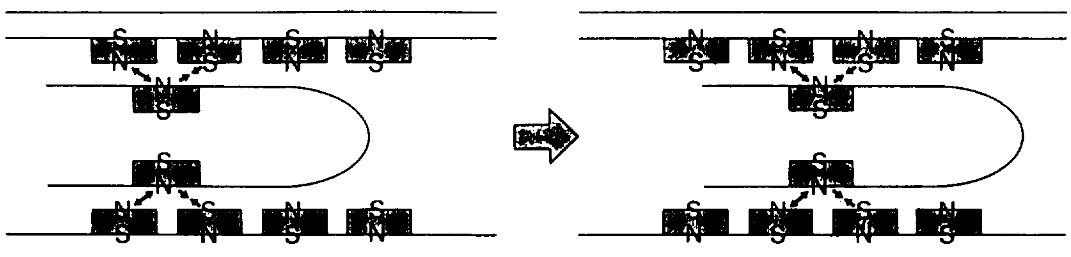
Principles of superconducting linear motor car MAGLEV

推進の原理

Principle of propulsion

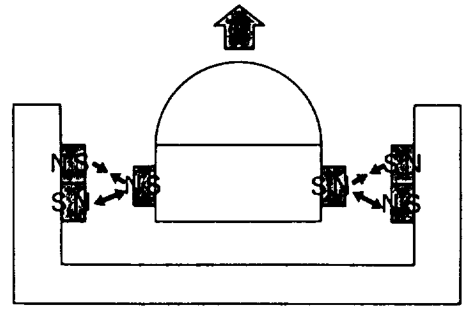
磁石どうしの反発力と吸引力を利用して車両(超電導磁石)を推進させます。ガイドウェイの両側の側壁に並べられた推進用のコイルに、変電所から電流(3相交流)を流すと、ガイドウェイに移動磁界が発生します。車上の超電導磁石がこれに引かれたり、押されたりして車両は進みます。

A repulsive force and an attractive force induced between the magnets are used to propel the vehicle (superconducting magnet). The propulsion coils installed on the side walls on both sides of the guideway are energized by the three-phase alternating current from a substation, creating a shifting magnetic field on the guideway. The on-board superconducting magnets are attracted and pushed by the shifting field, propelling the Maglev vehicle.



磁気浮上の原理

Principle of magnetic levitation

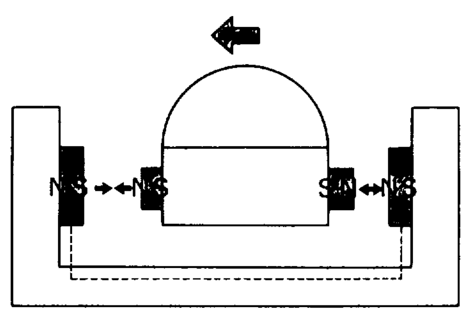


●上下の支持

走行路となるガイドウェイの側壁内側には、8の字の形をした浮上用コイルが取り付けられています。このコイルの中心から数cm下側を車上の超電導磁石が高速で通過すると、コイルに電流が誘起されて一時的に電磁石となり、超電導磁石を押し上げる力(反発力)と、引き上げる力(吸引力)が発生し、車両を浮上させます。

●Vertical suspension

The "8" figured levitation coils are installed on the side walls on the quideway. When the on-board superconducting magnets pass at a high-speed several centimeters below the axes of these coils, an electric current is induced within the coils, making them act as electromagnets temporarily. As a result, the forces which push the superconducting magnet upwards and ones which pull them upwards act simultaneously, thereby levitating the Maglev vehicle.



●左右の案内

向かい合う浮上コイルは、走行路の下を通してループになるように繋がれています。走行中の車両(超電導磁石)が左右どちらかに偏よると、このループに電流が誘起されて、車両が近づいた方の浮上コイルには反発力が、車両が離れた方の浮上コイルには吸引力が働きます。このようにして、走行中の車両は常にガイドウェイの中央を走行することになります。

●Lateral guidance

The levitation coils facing each other are connected under the guideway, constituting a loop. When a running Maglev vehicle, that is, a superconducting magnet, displaces laterally, an electric current is induced in the loop, resulting in a repulsive force acting on a levitation coil near the car and an attractive force acting on another levitation coil farther apart from the car. Thus, a running car is always located at the center of the guid-

MAGNETIC LEVITATION R&D at NASA

- In recent years, NASA and VPI (Virginia Polytechnic Institute) have provided support to the National Maglev Initiative (NMI) in the Department of Transportation's Federal Railroad Administration (FRA)
  - Support has been limited in scope, focusing on aerodynamics analyses of alternate maglev vehicle configurations
  - Other aeronautical technologies (structures, stability and control, noise, etc) are applicable
- Independently, NASA personnel have also examined various concepts and applications of magnetic levitation and related technologies for Agency purposes
  - **Wind tunnel model magnetic suspension and balance systems (MSBS) applications**
  - Magnetic bearings (superconducting and rare earth magnet) applications
  - High temperature superconductor materials and manufacturing (e.g., wire)
- Building on past studies, during the past 1.5 years, an intensive ad hoc examination has been conducted of the possibilities for application of maglev for space launch (i.e., the 'MagLifter' concept)
  - **The "MagLifter " concept:** Studies have focused on rocket-propelled vehicles
  - Potential applications include launch of small, medium and large Earth to Orbit (ETO) vehicles (Rocket, Airbreathing and Hybrid) as well as launch of hypersonics research X-vehicles)
  - **Coordination with USAF on the planned maglev upgrade of the high speed rocket-sled test track at Holloman AFB(a potential capability Mach 11+ using Maglev)**

Rationale for Maglev at NASA

NASA Systems-Level Space Opportunities

- Small Earth-to-Orbit Transportation ("Mark II" Catapults)
- Large Earth-to-Orbit Transportation ("Mark III" Catapults)
- Others

Dual-Use Technology Commercialization Systems-Level Opportunities — Aero/Space

- Maglev Ground Transportation
- Others

NASA Systems-Level Aeronautics Opportunities

- Hypersonics Research X-Vehicle Launcher ("Mark II" Catapult)
- Magnetic Suspension & Balance
- Hypersonic Test Track Research
- Others

Dual-Use / NASA Secondary Applications

- Magnetic Bearings (e.g., pumps, CMGs)
- Superconducting Materials Components (e.g., wire)
- Power Systems (distribution, storage, etc.)
- Potential Other Government Applications
- Others

Potential Impact of the Introduction of High-Temperature Superconductors

- High-Temperature (high 'Tc") superconductors could have major impacts in the areas of:
  - Cryogenics
  - Thermal stability of superconductor systems
  - Wire manufacturing and design
  - Vehicle magnetic shielding
  - System service and maintenance
- High Tc superconductors may also have moderate impacts in the areas of:
  - Levitation and guidance systems
  - System stress and fatique effects
  - Vehicle structure and suspension
  - Guideway system design trades/choices (e.g., power; curves; track type)
  - Design-Level issues (capital costs, operating costs, human factors)

Maglev-MagLifter R&D Program Concept
Mapping Strategic Goals into Technology Objectives

	MagLifter (Space Launch)	Aeronautics (R&D Applications)	Maglev (Ground Transport)	Secondary Opportunities
High-Leverage R&D Opportunities	**Laboratory-Level Proof-of-Concept** Low Mass Superconductors High Tc Superconductors High-Efficiency EM Propulsion	**Laboratory-Level Proof-of-Concept** Low Mass Superconductors High Tc Superconductors High-Efficiency Prop.	**Laboratory-Level Proof-of-Concept** Low Mass Superconductors High Tc Superconductors High-Efficiency Prop.	**Laboratory-Level Proof-of-Concept** Low Mass Superconductors High Tc Superconductors (Mfg, Components)
Core Technologies and Capabilities	**Testbed Demonstrations** Very High-Acceleration EM Propulsion Low-Cost Guideway Light-Weight Vehicles	**Testbed Demonstrations** High-Acceleration EM Propulsion Low-Cost Guideway Light-Weight Vehicles	**Testbed Demonstrations** High-Acceleration EM Propulsion Low-Cost Guideway Light-Weight Vehicles	**Testbed Demonstrations** Magnetic Bearings SMES Precision Tunnel Systems CMGs
Technology and Systems Validation	**System-Level Demonstration** Mark I Demo Mark II Demo (R&D for Mark III development)	**System-Level Demonstration** Hypersonic Test Track Experiments Sub-Scale Launch Demo (Mark II scale)	**System-Level Demonstration** Relevant System-Level Demos (Mark I, Mark II)	n/a

MSBS Applications

Support Interference-Free Aerodynamic Testing

- Transport cruise drag
- Generic interference evaluation
- High angle-of-attack aerodynamics
- Dynamic stability

Dynamic Stability Testing

- Forced oscillation - unlimited trajectory opportunities
- "Modal" oscillations
- Random excitation - system identification

Unsteady Aerodynamics

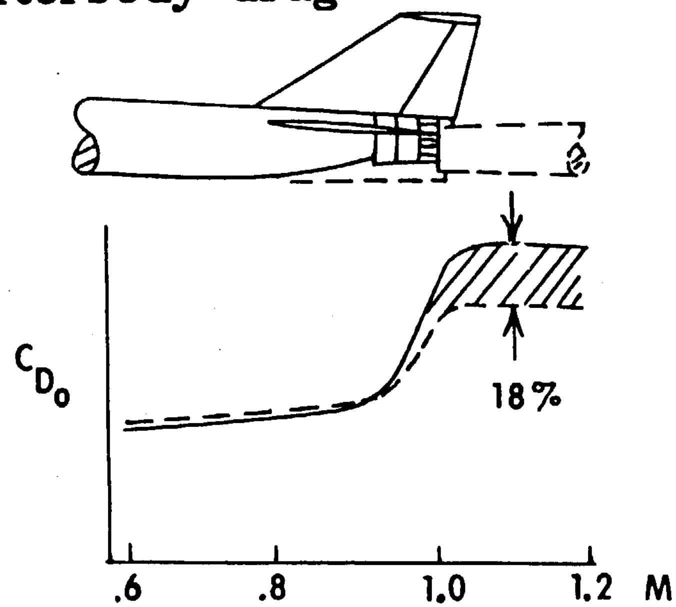
- Vortex flows / vortex breakdown
- Dynamic stall
- Unsteady separation and wakes

Unconventional Testing

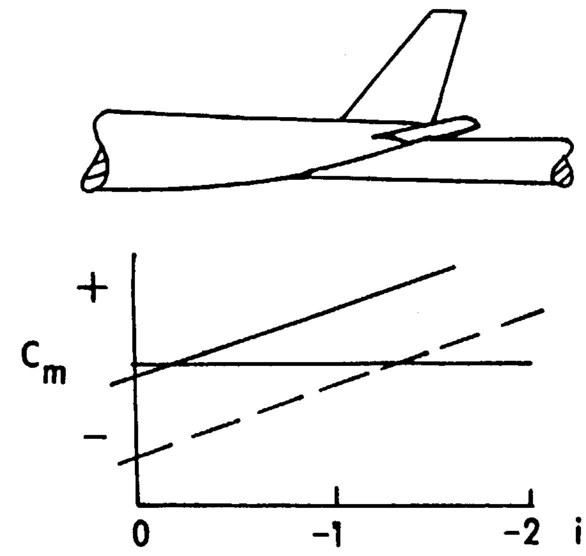
- Store separation.
- Multi-body separation

EXAMPLES OF SOME MODEL SUPPORT PROBLEMS

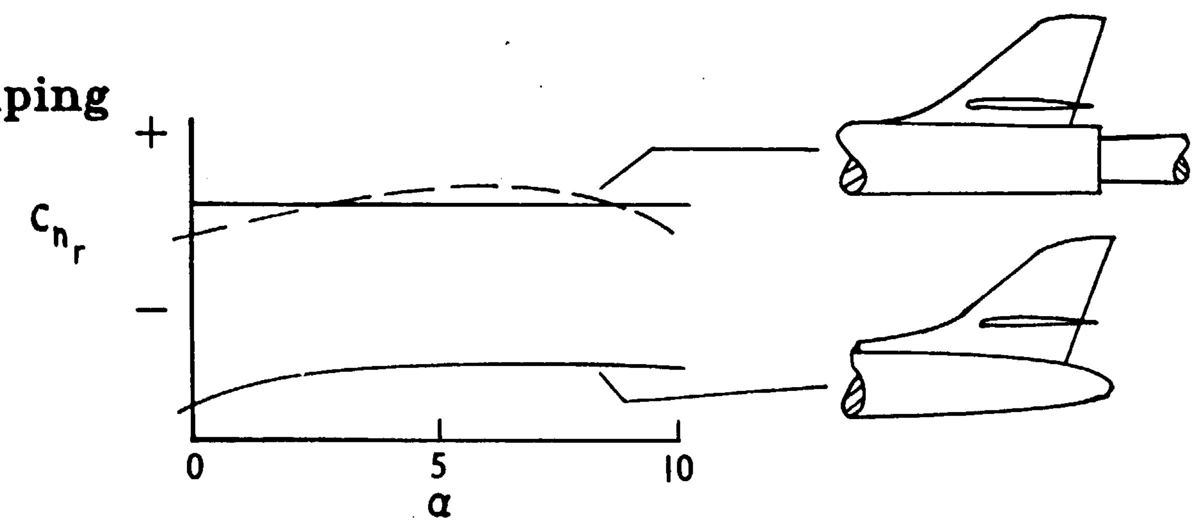
- Afterbody drag



- Trim & tail loads



- Yaw damping



Future Applications
Program Focus

Aerodynamics	Unsteady aerodynamics, dynamic stability, support interference elimination, unconventional testing
Technology development	MSBS is a powerful technology driver
Specific Technologies	Position and attitude sensors; control systems and algorithms; magnetic configurations; electromagnet design and analysis; superconductivity
Key Spin-Off Technology	Powerful, AC-capable, high temperature superconducting electromagnets

TRACK MISSION

- SIMULATES BY MEANS OF ROCKET SLEDS
  - Critical portions of flight trajectories
  - Dynamic events
  - Special environmental conditions
- BRIDGES THE GAP BETWEEN LABORATORY AND FLIGHT
- SHIFT RISK OF FAILURE FROM FLIGHT TO GROUND TESTING

TRACK CHARACTERISTICS

- Length: almost 10 miles!! Sled velocities at 10,000 ft per sec
- Two rails: 50,788 feet
- Narrow gage rail: 15,200 feet
- Gages: 7 feet and 26.31 inches
- Alignment: withing 0.005 inch
- Continuously welded

PROVEN TEST CAPABILITY

AIRCRAFT

- Crew Escape
- Airblast
- Birdstrike
- Aeropropulsion
- Munitions Launch
- IRCM

MISSILES

- Guidance
- Aerodynamics
- Aeroelastics
- Dispenser
- Seekers
- Components

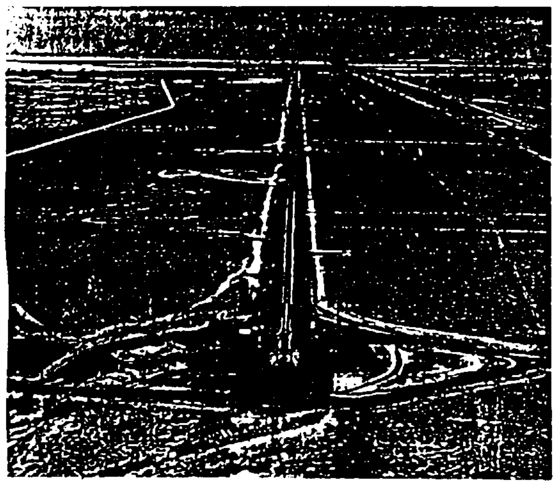
ENVIRONMENT

- Rain / Ice
- Aerothermal
- Dust
- High G
- Hypersonic

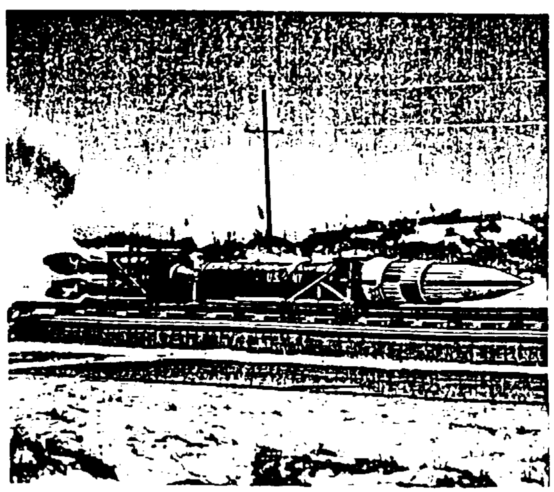
OTHER

- Warhead / Fuse
- Impact
- Decelerators
- Survivability
- Vulnerability
- Lethality
- Live Fire

HOLLOMAN
HIGH SPEED TEST TRACK



"ON TRACK FOR TOMORROW"



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***TEST VELOCITIES*: Sled velocities approaching 10,000 feet per second**

ADVANTAGES OF TRACK TESTING

- Full-Scale Testing
- Realistic Simulations
- Accurate/Timely Results
- Cost-Effective Approach
- Flight-Test Environment
- Test Item Recovery
- Testing of Prototypes
- Early Development Risk Reduction

HOLLOMAN TEST TRACK - WHY MAGLEV?

- CURRENT CAPABILITY:
  - 1.5 - 2.4 KM/SEC
  - VIBRATIONS MAY EXCEED FLIGHT ENVIRONMENT
- LIMITATIONS
  - RAIL INDUCED LOADS/IMPACTS
  - PROPULSION
  - SLIPPERS
  - - - - - - - - - - - - - - - - - - - "*and with MAGLEV capability*"
- ELIMINATES RAIL IMPACT INDUCED LOADS/ VIBRATION
  - PAYLOADS CAN BE MORE REALISTIC
  - REDUCED SLED STRUCTURE
  - HIGHER VELOCITIES: 3.5 KM/SEC +
- ELIMINATES SLIPPER WEAR

HOLLOMAN AFB MAGLEV TRACK UPGRADES

Option 1: Extend existing track 7 km
speed capability 2.5 km/sec → 2.7 km/sec
Vibration Levels Unchanged

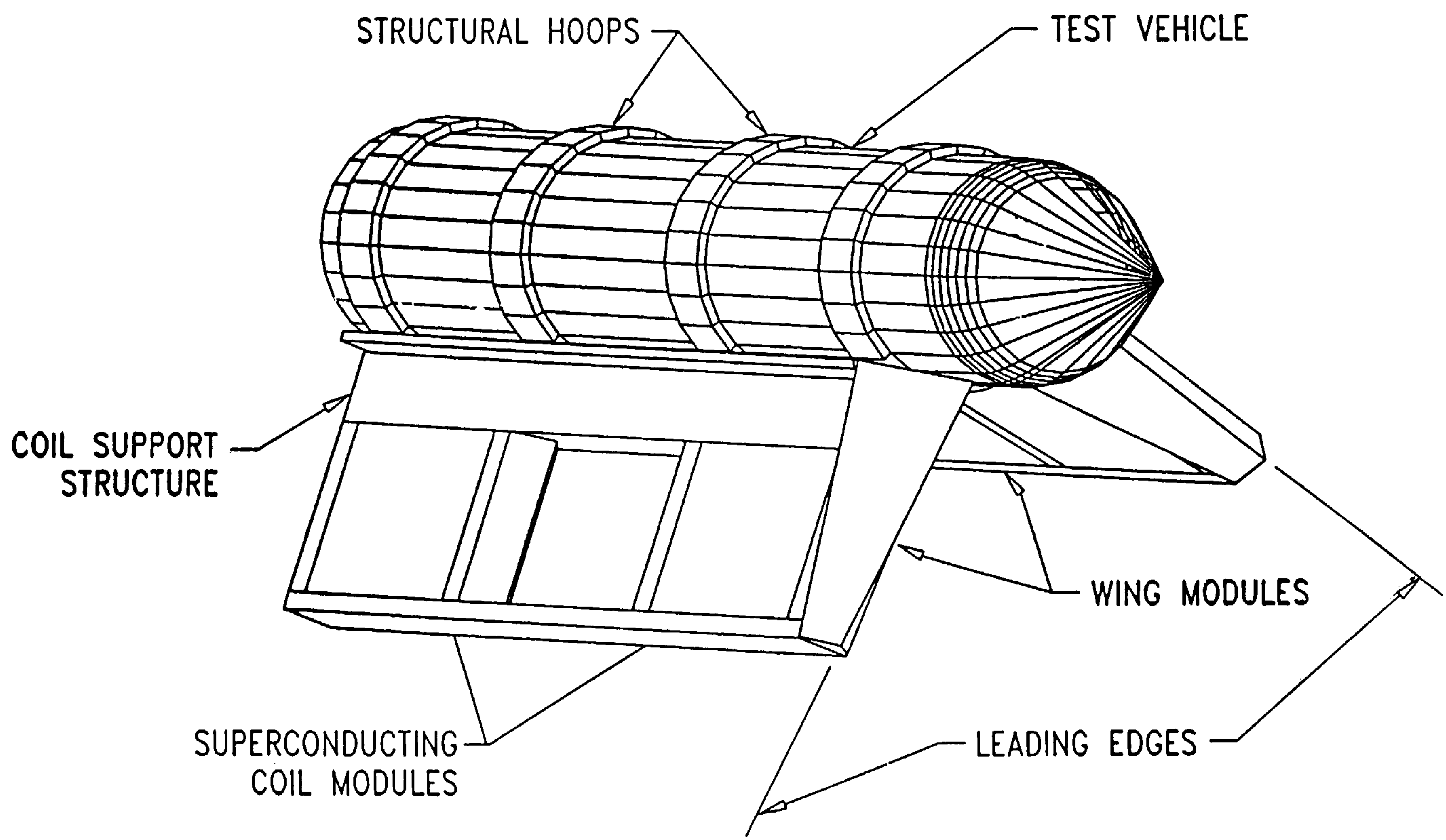
Option 2: Extend existing track 7 km
use MAGLEV on extension
speed 2.5 km/sec → 3.5 km/sec
Much Reduced Vibration

Option 3: Extend existing track 9 km
use MAGLEV on extension
speed 2.5 km/sec → 3.7 km/sec
Much Reduced Vibration

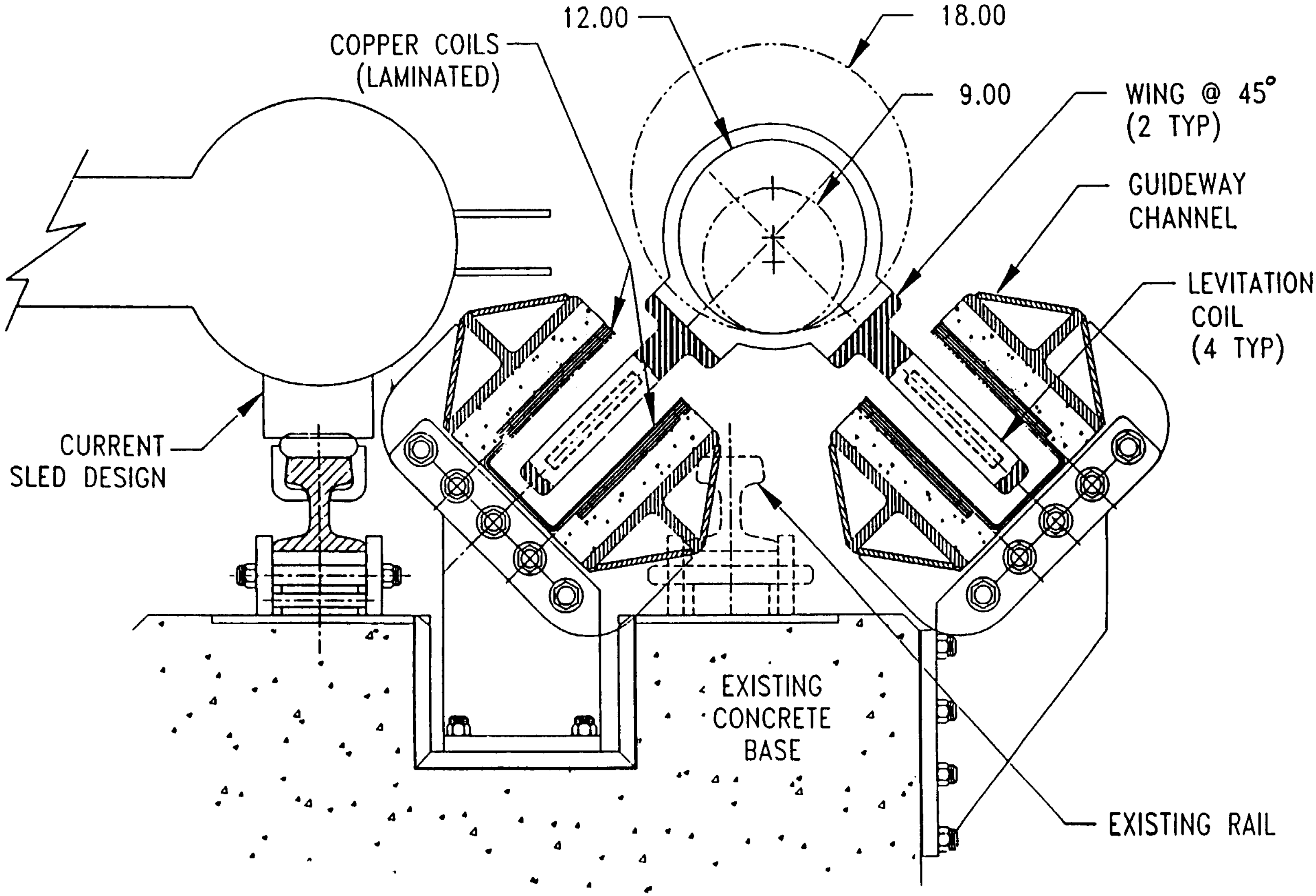
POTENTIAL HYPERVELOCITY MAGLEV APPLICATIONS

- HYPERVELOCITY IMPACT STUDIES (3 - 4 KM/SEC
  - Lethality Tests
- FIRST-STAGE BOOST OF ORBITAL AND SUB-ORBITAL PAYLOADS
  - Environmentally compatible launch systems
- FLIGHT TESTS/WIND TUNNEL TESTS AT HYPERVELOCITY
  - Piggy - back experiments (free-flight cone-cylinders)
  - Tests of models at full-scale
  - Boundary Layer Transition (no tunnel noise, M8)
  - Materials/Actively Cooled structures
- HIGH AERODYNAMIC EFFICIENCY PROJECTILES USING AIR-BREATHING ENGINES - storable hydrocarbon fuel scramjet testing to Mach 11 + in non-vitiated air and $q > 10,000$ (T/W = 100/200)

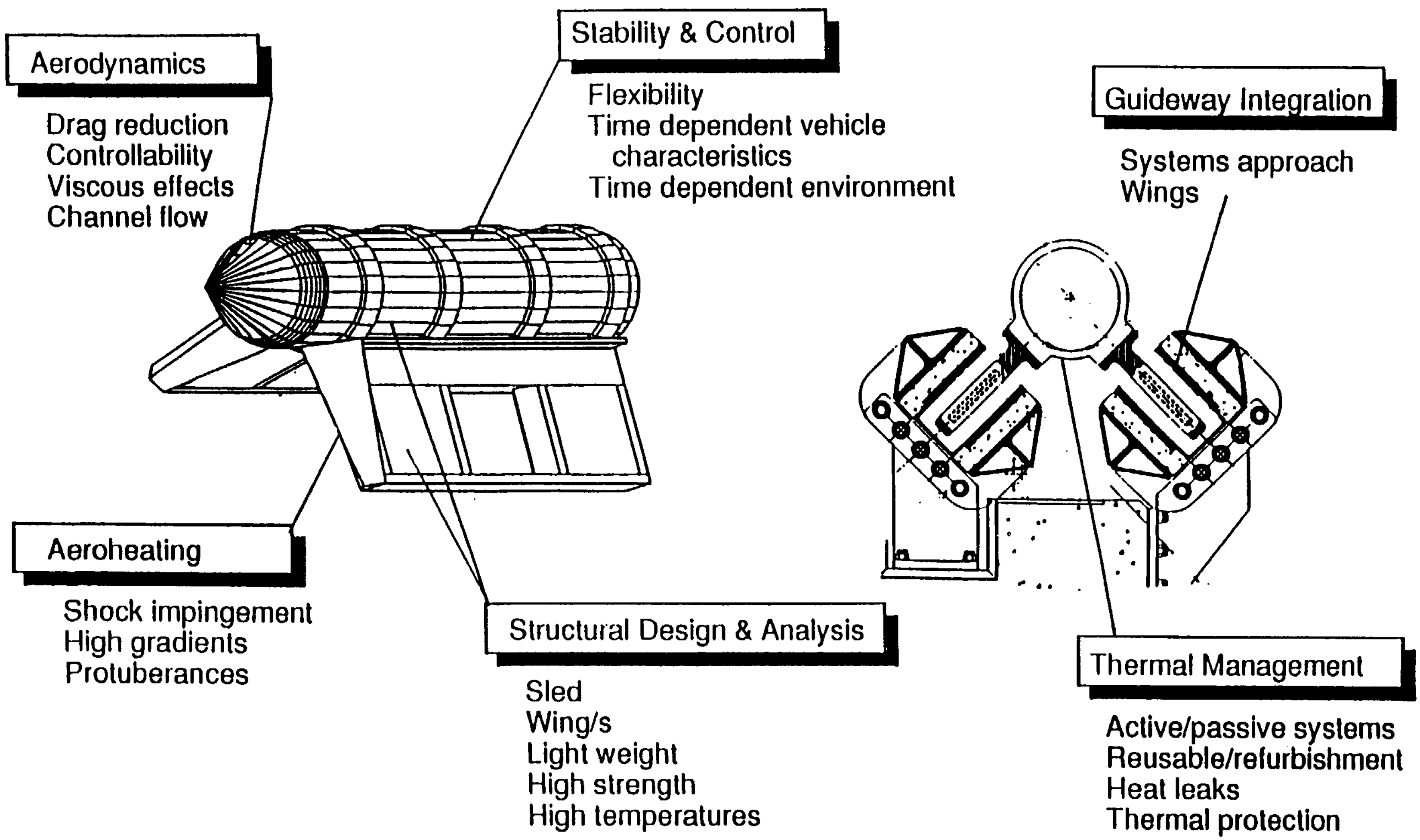
LEVITATED TEST SLED ASSEMBLY



LEVITATED ROCKET SLED RAILS
(Double Wing at 45°)



MAGLEV HIGH-SPEED ROCKET SLED DESIGN ISSUES

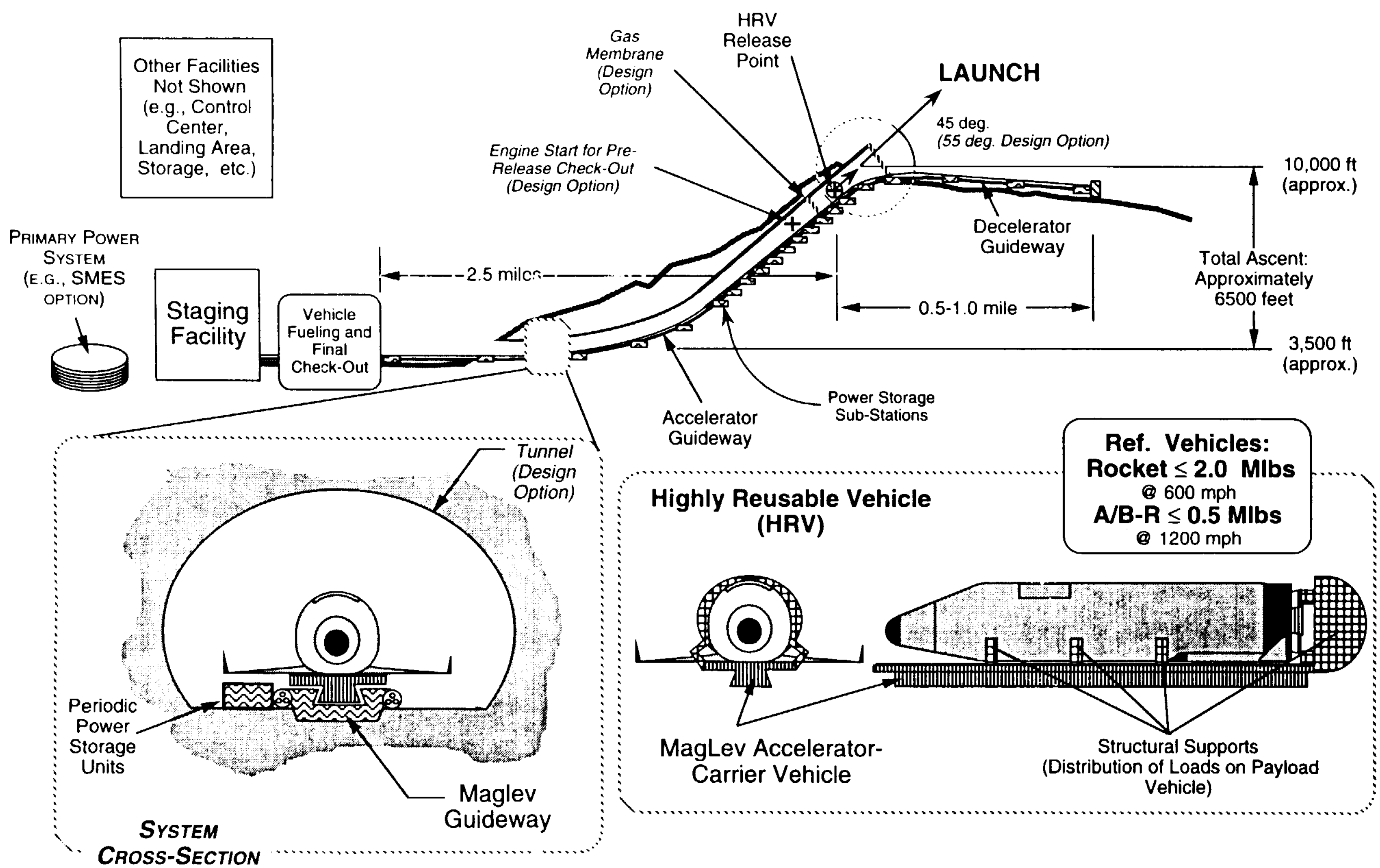


PICTURE of

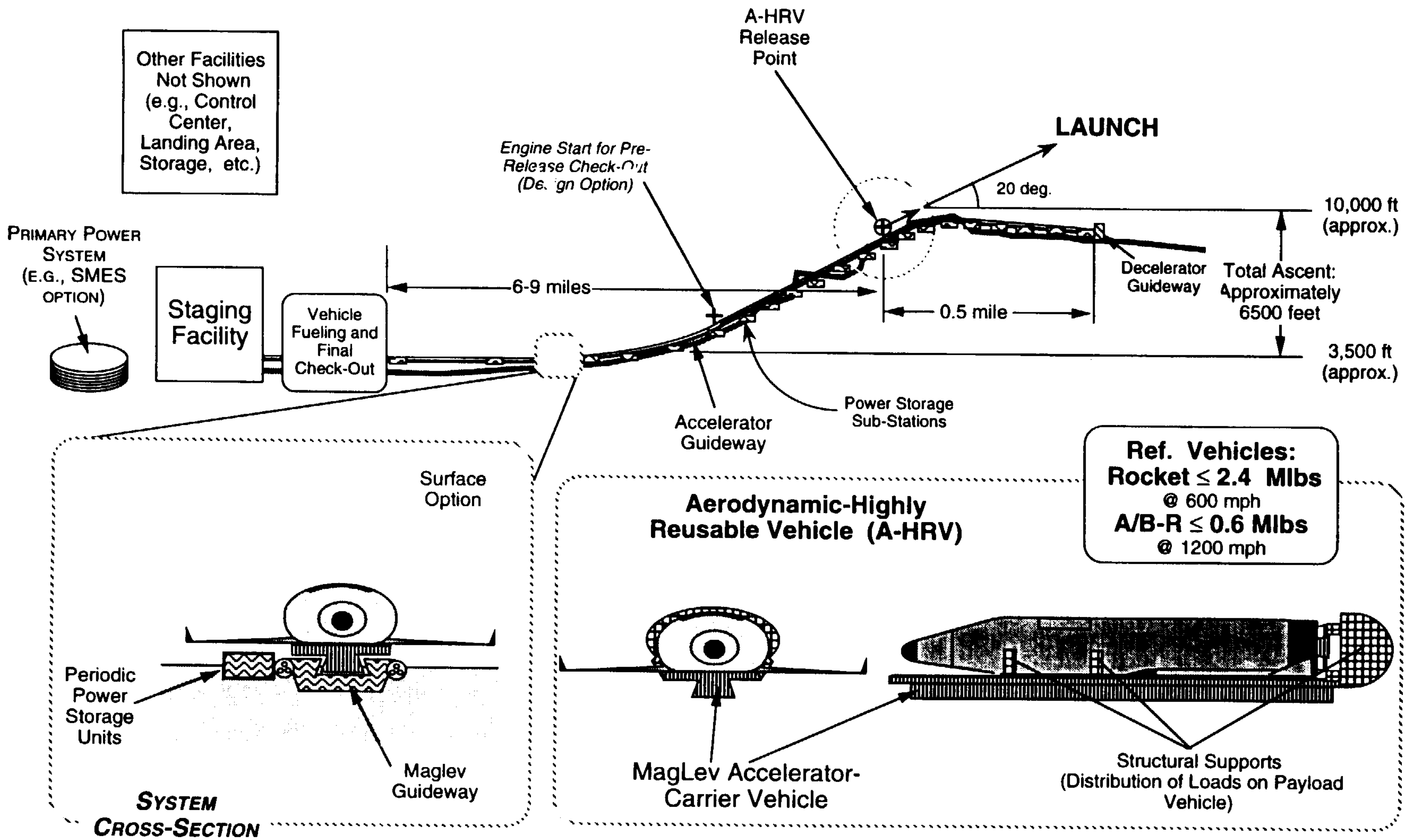
MAGLIFTER CONCEPT

MagLifter — non-Aerodynamic HRV

Configuration A "Mark III" Full-Scale System

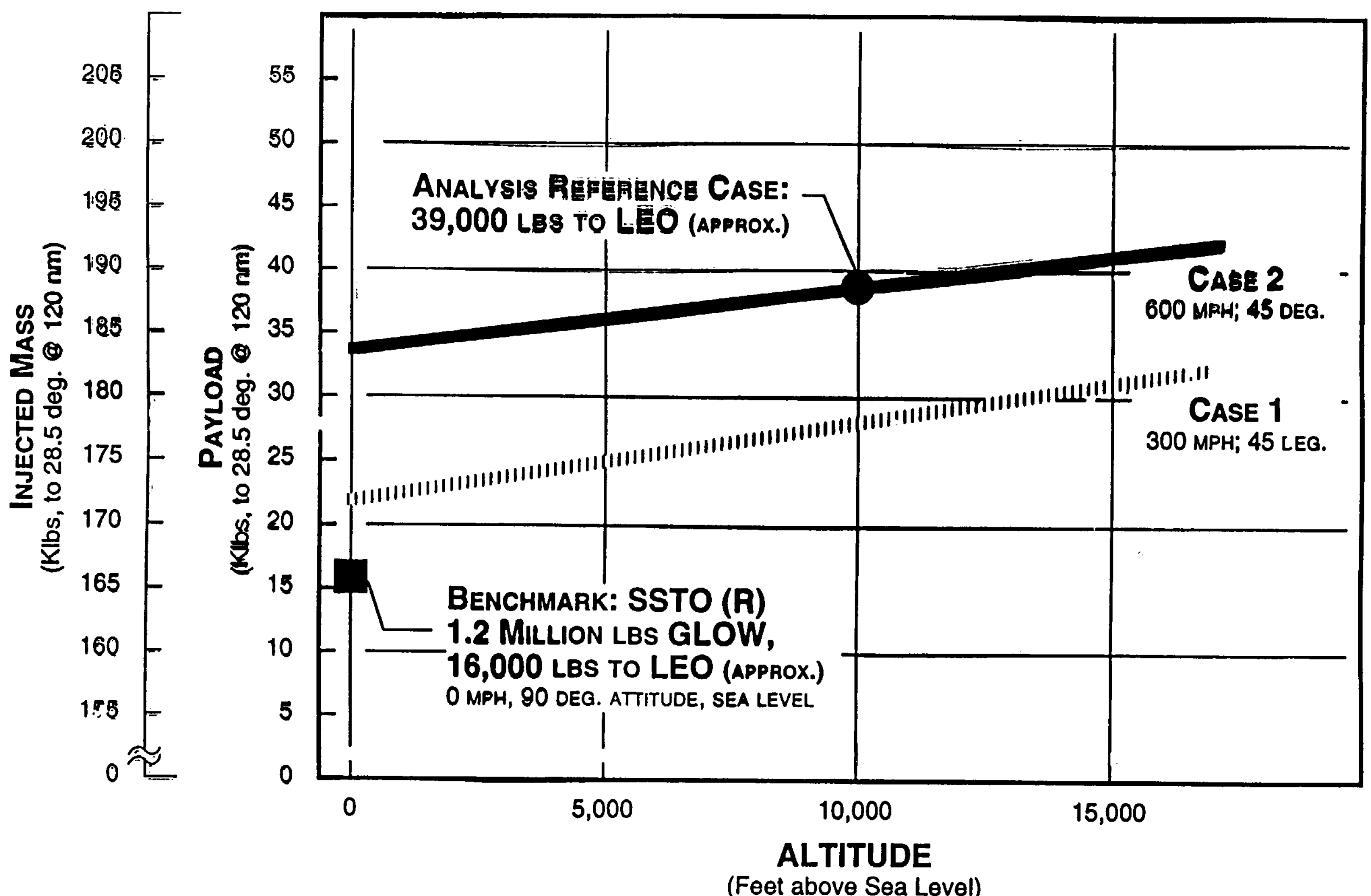


MagLifter — Aerodynamic HRV
Configuration B "Mark III" Full-Scale System



MagLifter – Payload Sensitivity Analysis

(Sensitivity to Altitude and Velocity)



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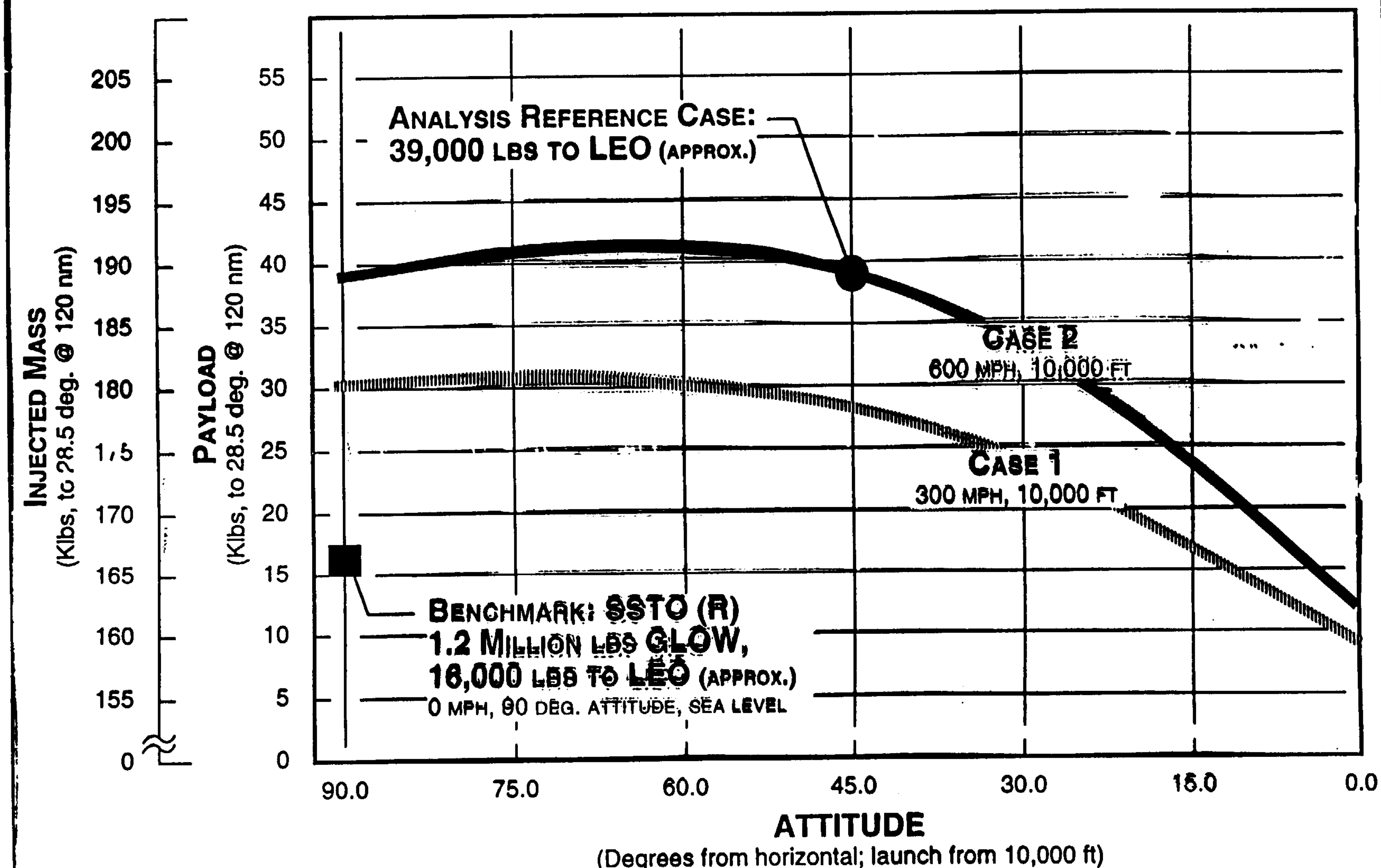

MASS TRANSPORTATION MAGLEV

RECENT DEVELOPMENTS IN JAPAN

Selected Maglev Technology Issues

- The following are some of the key technology-related issues facing maglev applications for ground transportation
  - Aerodynamics (ie., reducing drag at high speeds; entering/exiting tunnels)
  - Communications with the vehicle; control of the vehicle
  - Magnet design, cryogenics, helium management
  - High speed switching; speed, acceleration and braking
  - Primary and secondary suspension
  - On-board power; system power supply (interface with utility, substations)
- Other key design and development issues include:
  - System development and implementation cost (guideway, vehicles)
  - Magnetic field levels in the vehicle (passenger safety)
  - Passenger ride quality (transient g-forces inside the vehicle)
  - Route selection and system operations
  - 'Operations and maintenance' of the system (logistics, cost, emergencies)
  - Noise (inside the vehicle, outside the vehicle)

Major R&D task: make construction costs competitive with that of the conventional wheel - rail system.