Magnetic Launch Assist – NASA's Vision for the Future (May 2000)

William A. Jacobs, PE

Abstract-- **With the ever-increasing cost of getting to space and the need for safe, reliable, and inexpensive ways to access space, The National Aeronautics and Space Administration (NASA) is taking a look at technologies that will get us there. One of these technologies is Magnetic Launch Assist (MagLev). This is the concept of using both magnetic levitation and magnetic propulsion to provide an initial velocity by using electrical power from ground sources. The use of ground generated electricity can significantly reduce operational costs over the consumables necessary to attain the same velocity. The technologies to accomplish this are both old and new. The concept of MagLev has been around for a longtime and several MagLev Trains have been developed. Where NASA's MagLev diverges from the traditional train is in the immense amount of power required to propel this vehicle to 183 meters per second in less than 10 seconds. New technologies or the upgrade of existing technologies will need to be investigated in the areas of energy storage and power switching. An added difficulty is the separation of a very large mass (the space vehicle) from the track and the aerodynamics of that vehicle while on the track. These are of great concern and require considerable study and testing. NASA's plan is to mature these technologies in the next 25 years to achieve our goal of launching a full sized space vehicle for under $300 a kilogram.**

Index Terms—**Magnetic Launch Assist (MagLev), National Aeronautics and Space Administration (NASA), Launch Systems, Space Vehicles.**

Manuscript received May 1, 2000. This work was supported by the National Aeronautics and Space Administration.

William A. Jacobs is with the National Aeronautics and Space Administration, MSFC, AL 35812 USA (telephone: 256-544-3522, e-mail: bill.jacobs@ msfc.nasa.gov).

I. Introduction

ACCESS to space is becoming increasingly more expensive. A Shuttle mission typically costs more than $400 million per flight. In order to lower the cost to space we must find cheaper methods of transportation to get us there. The National Aeronautics and Space Administration (NASA) has a program called the Advanced Space Transportation Program (ASTP) to develop technologies in the next 25 years that will improve safety and reliability by a factor of 10,000 while reducing the cost for space access by a factor of 100. Among these technologies is the area of launch assist. Magnetic levitation and propulsion has been viewed as a *safe, reliable, and inexpensive* launch assist for sending small payloads into orbit.

II. Why MagLev?

Magnetic Levitation has been considered for many years as a next step for train systems. The method of electrical propulsion eliminates the need for fossil fuels and reduces the amount of pollution expended into the atmosphere. Also the non-contact nature of the track allows for longer life of the track and greater speeds for the trains. During the past decade NASA has been studying ways of assisting the launch of space vehicles. The advantage to launch assist is that by providing an initial velocity to the space vehicle it is possible to save over 20% of the onboard fuel. That translates to savings in fuel cost, and vehicle weight. Also by lowering the amount of fuel you can add more payload, reduce the size of the vehicle, or build a stronger more robust vehicle. Several methods of assist had been studied such as balloon launch assist, aircraft assisted launch, pneumatic launch assist, magnetic launch assist, and others. Due to the requirements set forth in the launch assist program, the most viable approach was magnetic launch assist. For the same reasons the train industry has looked at maglev, NASA requires a low maintenance, inexpensive, environmentally clean, safe, and reliable system. It is thought that maglev will deliver best on these goals.

III. Approach

Although this method of launch assist seems the best approach considering the requirements set forth, it still has many challenges. The present goals state that a 55,000 Kg vehicle shall be accelerated at 2 times the acceleration due to gravity to reach a speed of 183 meters per second before separating. Assuming that the carrier weight is half that of the vehicle we get the following energy requirements.

$$TotalMass(mt) = 82{,}000Kg$$

$$Force(f) = mt * a = 1.6 \cdot 10^6 N$$

$$AccelerationTime(t) = 183mps/a = 9.34s$$

$$Finalpower(p) = f * 183mps = 2.93 \cdot 10^5 kW$$

$$TotalKineticEnergy(KE) = \frac{p}{2} * t = 1.4 \cdot 10^9 Joules$$

Assuming a 50% efficiency of the system, the total energy is closer to 3,000 Mega Joules. This is a tremendous amount of energy that is required in 9.3 seconds. The ability to store this amount of energy and then quickly distribute it to the track will be among the numerous technical challenges. Along with the energy challenges the current track configurations must be able to scale up to the present goals of the full scale system and vehicle/cradle dynamics must be investigated. The present approach NASA is taking falls along these lines. The approach is to develop magnetic levitation, and linear motor technologies to investigate; scaled concepts representative of the future goals; stability and control over the operating range of the system; integration and interaction between the thrust cradle and the vehicle; energy storage and distribution concepts over the operating range; and development of a full scale technology demonstrator.

In order for this approach to be accomplished, NASA has contracted with three companies to initially produce magnetic levitation concepts; Foster-Miller out of Waltham, MA; Lawrence Livermore National Laboratory, out of Livermore, CA; and PRT Advanced MagLev Systems, Inc. out of Park Forest, IL. Each of these contracts was to show a small demonstration of their concepts at the conclusion of the first phase.

IV. Concepts

The concept envisioned by Foster-Miller (FM) uses a Linear Synchronous Motor (LSM) for propulsion and null flux coils reacting against a magnetic field for levitation. As a full scale system, the magnetic field will be developed through the use of super conducting coils in order to achieve greater flux densities than rare earth permanent magnets. Foster-Miller developed a 13 meter proof of concept. This track, as seen in ***figure 1***, uses rare earth permanent magnets in the cradle and both the drive and levitation coils are on the track. The cradle weighs 6 Kg and achieves a top speed of 97 kph at the six and a half meter mid point. The drive coils are located in the first 6.5 meters of the track and aluminum bars are used for braking in the second 6.5 meters. The movement of the flux field past the null flux coils achieves the levitation. The center of the field is below the center of the coils at rest. As the carrier/magnet field moves past the null-flux coils a magnetic field is produced at the center of the coils. This field causes the center of the carrier's magnetic field to align with it thereby lifting the carrier.

Lawrence Livermore's concept also employs the use of permanent magnets. The permanent magnets are rare earth magnets aligned in a manor that combines the flux densities on one side and cancels them on the other. This alignment is called a Halbach array. This array of magnets is located on the horizontal portion of the carrier. Unlike the Foster-Miller approach, it is expected that the array will still use rare earth permanent magnets on the full scale system rather than using super conducting magnets. The track consists of coils used for levitation interleaved with drive coils for the vehicle propulsion. Propelling the carrier and magnets across the levitation coils causes a current in the coils that creates an opposing field against the Halbach array producing the levitation. To propel the carrier the drive coils are powered sequentially down the track with resonant charging capacitors, which increase in frequency as the carrier gets faster. The concept demonstrator seen in ***figure 2*** shows a track with propulsion coils in the first meter of the track and levitation coils in the next 20 meters. The cradle is 20Kg and achieved a top speed of 43 kph. For the next phase the drive coils will be interleaved with the levitation coils and the carrier is also being redesigned for greater stability as shown in ***figure 3***. There are three sets of arrays on this carrier. One on the horizontal portion for levitation and one on each lower portion for stability. All three of the arrays will be used for motor thrust.

The concept designed by PRT varies from the other two concepts. The PRT design employs the use of AC power as an alternative to DC power or permanent magnets. The AC power flows through the coils found, in ***figure 4***, on the horizontal portion of the track. This creates opposing magnetic fields in the aluminum channel on the carrier to produce levitation. The movement of the electric field allows the carrier to levitate while remaining motionless. This would be termed an active levitation system as opposed to the other passive systems which produce levitation through the movement of the carrier. The propulsion is produced using a three-phase linear induction motor (LIM). The motor coils are also found on the track and are located in the vertical central portion. The motor is a toothless diamond shaped coil design called the waffle motor. The traveling three-phase field reacts against an aluminum plate on the carrier to produce thrust down the track. The phase one concept is 15 meters long. The first 7.5 meters are used for propulsion and the second 7.5 meters are used for braking. The carrier is 58Kg and achieves a maximum speed of 45 kph. In the next phase the track will be extended to 61 meters and go from a single track to a dual style track as shown in ***figure 5***. This track will also employ inverter control, which will be used to maintain the peak slip frequency as the carrier increases in speed.

V. Next Step

As the MagLev designs continue to progress, research into energy storage systems and distribution systems are also being pursued. Numerous technology programs are looking into flywheel energy storage, capacitor energy storage and magneto-hydrodynamic energy storage systems as well as others. Many organizations are developing electro-magnetic launch systems that require some of the same components as NASA's Magnetic Launch Assist. Although many of these systems are smaller in size, research in these areas will definitely aid to further advance the technologies NASA requires. Aerodynamic modeling and analysis are beginning to be looked into to understand the dynamics involved in sending a lifting body vehicle down a track at high speeds and then separating from the carrier. This is a key element for evolving to a full scale system since the dynamics are not clearly understood. The first of many small-scale flight tests will be performed around the end of 2001. Track development for a medium scaled demonstrator will begin around 2002 with flights expected in 2005. Development of the full-scale demonstrator will begin in 2006 and should be ready for flight demonstration in 2010.

VI. Conclusion

Magnetic Levitation and propulsion technologies have been around for decades. But there is still a long way to go. The three concepts will continue to be developed and refined as they grow in size. The technical challenges associated with this development are being tackled by many organizations for different reasons but will aid in all efforts. As NASA embarks on greater missions with smaller budgets, the need for cheaper access into space is of great importance. The use of Magnetic Launch assist will be one of the elements that will help us reach our goals.

Acknowledgment

I wish to thank the Advanced Space Transportation Department for allowing me to work on this program and aid in it's development. I also wish to thank the coordinators of the 10th EML Symposium for asking me to speak on behalf of NASA's program in Magnetic Launch Assist.

References

[1] Jose Perez-Morales, Kennedy Space Center, KSC, FL, personal communication, 2000.

[2] James Dill, Foster-Miller, Waltham, MA, personal communication, 2000.

[3] Louann Tung, Lawrence Livermore National Laboratory, Livermore, CA, personal communication, 2000.

[4] George Scelzo, PRT Advanced MagLev Systems, Inc., Park Forest, IL, personal communication, 2000.

[5] William Dawson, University of Sussex, Brighton, Sussex, UK, personal communication, 2000.

[6] Denis Edwards, University of Sussex, Brighton, Sussex, UK, personal communication, 2000.

[7] Steve Cook, Marshall Space Flight Center, Huntsville, AL, personal communication, 2000.

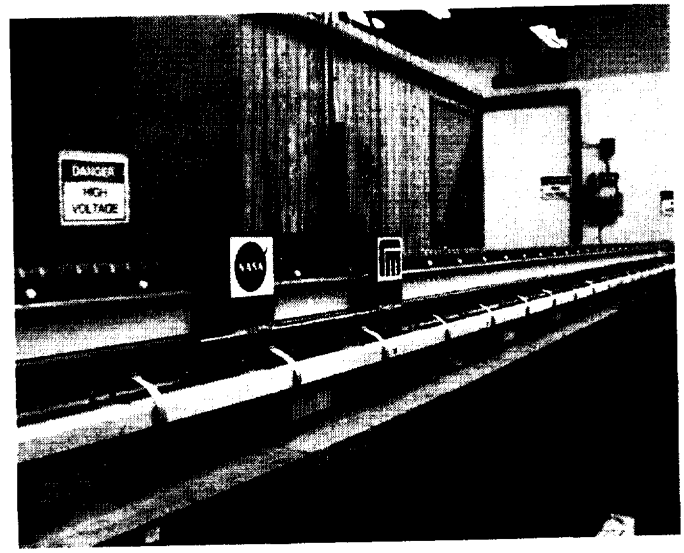

Figure 1. Foster-Miller's concept Demonstrator.

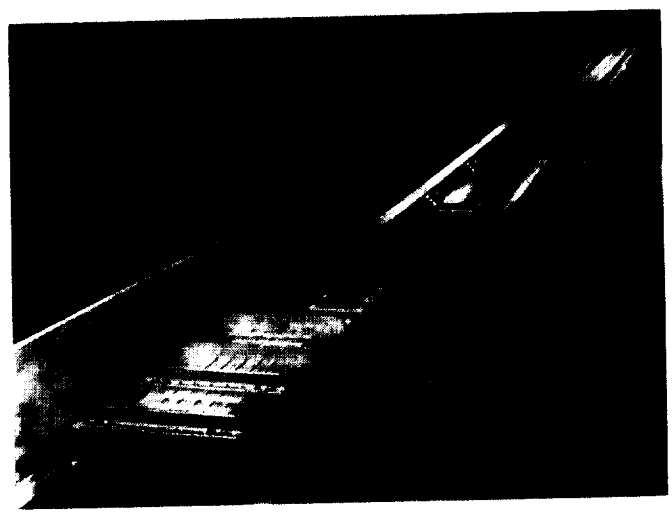

Figure 2. Lawrence Livermore National Laboratory's Concept Demonstrator

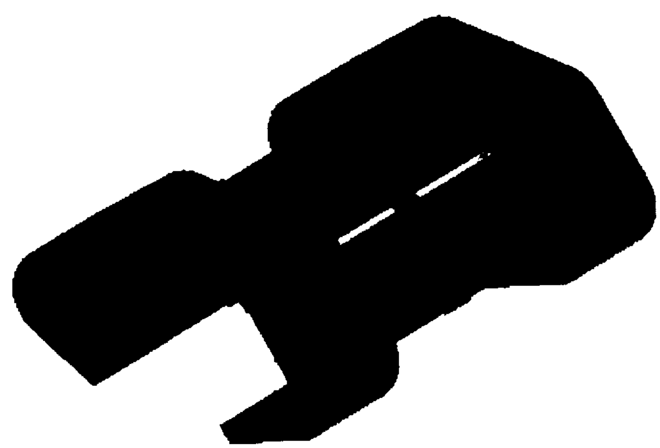

Figure 3. LLNL's Advanced Cradle Design

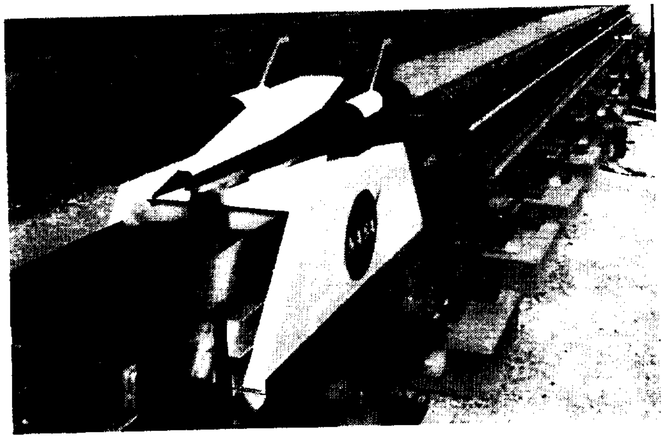

Figure 4. PRT Advanced MagLev Systems, Inc.'s Concept Demonstrator

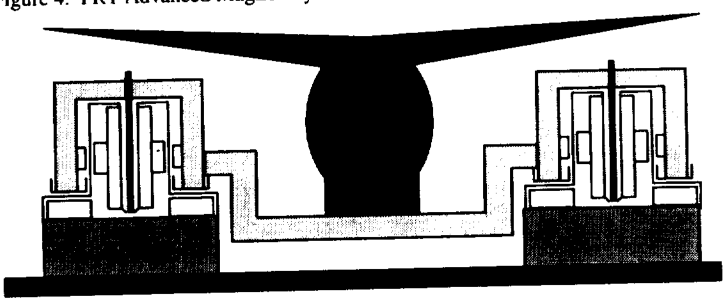

Figure 5. PRT's Dual Track concept