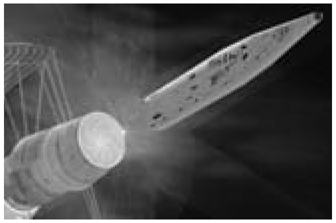
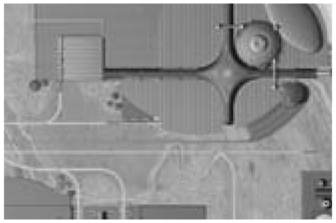
Spaceport Visioning

Concept Study

October 2002





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Introduction

The future holds great promise for further space exploration and commerce. One ongoing constraint in this endeavor is the cost of access to space. The Space Shuttle, the first-generation Reusable Launch Vehicle, has a launch cost to Low Earth Orbit of about $10,000 per pound. NASA has identified launch cost goals for the second-generation RLV vehicle of $1,000 per pound. Launch-assist systems using new technology may help reduce the cost of launching payloads into space. The Maglifter and Star Tram concepts propose horizontal launch-assist systems with superconducting magnetic levitation technology to propel RVLs into orbit, at a lower cost per pound. These two launch concepts and their spaceport implications are the subject of this report.

Objective

The objective of this study is to identify the spaceport implications associated with deploying MagLifter and Star Tram launch-assist systems at a terrestrial spaceport. The study will address basic spaceport issues, including spaceport feasibility and implementation hurdles. The resulting spaceport concepts will be depicted in graphic renderings. This study does not include assessing the feasibility of the MagLifter and Star Tram launch assist concepts.

Overview of Launch Concepts

MAGLIFTER

The MagLifter concept is the result of a design study initiated in support of a NASA study on Highly Reusable Space Transportation (HSRT). MagLifter is a launch system comprising a launch-assist component and a space flight vehicle designed to carry payloads to low Earth orbit and the International Space Station at a cost per pound significantly lower than is possible using current technology and equipment.

The MagLifter launch-assist system is envisioned to provide horizontal launch assist to spacecraft in much the same way a catapult assists in launching aircraft from an aircraft carrier. The launch system comprises a launch platform (sled) that can be accelerated along a 2.3-mile fixed guideway. The sled carries a powered space flight vehicle that is launched as the sled reaches maximum velocity, approximately 550 miles per hour. After engine ignition, the flight vehicle separates from the sled and begins a powered ascent to Earth orbit, while the sled decelerates on the guideway and stops before returning to the starting position to be readied for another launch.

The launch-assist system derives its MagLifter name from the superconducting magnetic levitation and propulsion technologies on which its operation is based - technologies similar to those in operation and under development for high-speed MagLev passenger transportation systems. Rows of large superconducting magnets line both sides of the sled bottom and react with continuous conductive plates fixed to the guideway, creating repulsive magnetic forces strong enough to "float" the combined 1-million-pound weight of the sled and largest flight vehicle more than 95 millimeters above the guideway surface. The sled is propelled by superconducting propulsion coils aligned along the center bottom of the sled, which interact with a continuous three-phase linear synchronous motor winding in the center of the guideway. The propulsion system accelerates the sled and mated flight vehicle at a constant two-times-gravity (2G) rate to 550 miles per hour. After launch, the system decelerates the sled and returns it to the starting point.

The concept flight vehicle, Argus, is a horizontally launched swept-wing craft powered by two supercharged ramjet (SCRJ), rocket-based combined-cycle (RBCC) engines using liquid hydrogen and liquid oxygen fuels. The engines are capable of efficient operation as air-breathing jets at grade, as well as pure rocket mode at highest ascent altitudes. Argus size configurations vary from 170 to 225 feet in length, with a 51- to 60-foot wingspan. Fully loaded with cargo and fuel, Argus weighs from 600,000 to 1 million pounds. The baseline configuration (smaller size) can deliver 20,000 lbs. to low Earth orbit or 11,100 lbs. to the International Space Station, with the option of inserting a passenger module into the payload bay to transport six passengers. Argus returns from orbit as a glider, similar to the current Space Shuttle fleet, but has an onboard landing engine to facilitate in-flight maneuvering or taxiing upon landing on a conventional runway. -see figure 1 (next page)

Figure 1

Maglifter Launch Vehicle-Argus

MagLifter technology represents an advance beyond current launch methods by effectively replacing the first stage of a conventional launch vehicle, resulting in lower launch vehicle weight, higher payload capacity and lower per-pound-to-orbit launch costs. Additionally, MagLifter is completely reusable, able to recycle between launches within eight hours. It is robust, requiring only occasional routine maintenance between launches and more extensive maintenance once a year after several hundred launches.

The potential benefits of the Maglifter concept towards making access to space more routine and affordable include:

1. A flight element or first stage is replaced by a ground system. This exchanges what is typically fragile, weight sensitive, complex flight systems with robust, "boiler-plate" ground infrastructure.

2. The use of superconducting magnetic levitation adds significant margin to the concept. The tolerance from sled to rail is substantially greater than non-superconducting systems. Further, the use of superconducting magnets may significantly reduce any design pressure to make a sled that is light-weight. Again, a more robust system is possible.

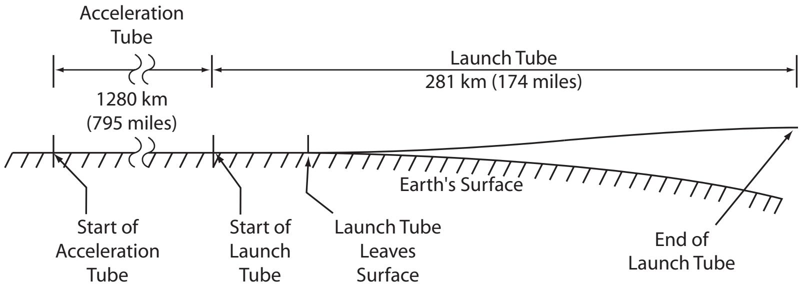
3. The system can be incrementally tested and matured. This may lead to more effective designs for flight and ground systems as the engineering test-fail-fix cycle can be more extensive and rigorous within reasonable cost limits. It is not necessary to launch all the way to orbit for a first flight of elements never before integrated together, as is done routinely with rockets.

STAR TRAM

Star Tram is a revolutionary new launch-assist concept developed by Dr. James Powell of Star Tram Incorporated. The Star Tram concept utilizes superconducting (SC) cables to levitate a 7-meter (23-ft.) diameter evacuated launch tube to an altitude of 22 km (72,000 ft.) above sea level. The launch vehicle is magnetically levitated and accelerated inside a long evacuated acceleration tube at ground level. The launch vehicle then coasts upward inside the magnetically levitated launch tube where it exits into the upper atmosphere. A subsequent burn from an onboard engine boosts the launch vehicle into Earth orbit. The scale of the Star Tram concept is enormous. The total length of the Star Tram launch tube is 1,561 km (969 miles). The system is divided into two main components: the acceleration tube, which is 1,280 km (795 miles) long and located on the earth's surface, and the launch tube, which is 281 km (174 miles) long with one end levitated to an altitude of 72,000 feet (see Figure 2 below).

Figure 2

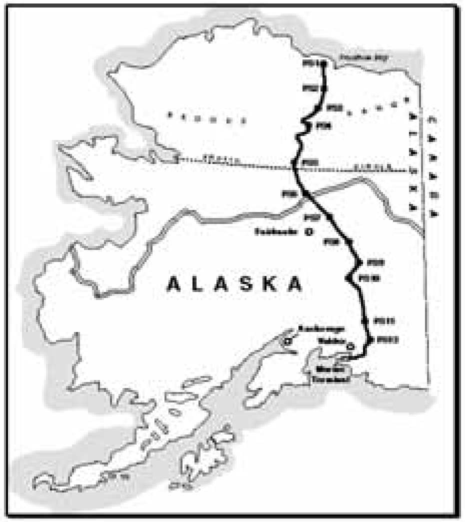
Star Tram Launch System



To put this distance in perspective, 1,561 km (969 miles) is the distance from Orlando, Fla., to New York City. For comparison, the Trans-Alaska pipeline covers 800 miles between the north slope of Alaska and the port of Valdez. (See Figure 3 below)

Figure 3

Trans-Alaska Pipeline



The 1,280-km-long, 7-m-diameter acceleration tube is evacuated to reduce atmospheric drag on the vehicle and the resulting deceleration and heat gain. Pump stations located approximately every kilometer along the length of the launch tube evacuate air from the system. Launch vehicles will enter the launch tube through an airlock system to maintain the low pressure inside the tube. The acceleration tube requires power in the tens of gigawatts range to accelerate the launch vehicle to 8 km/second (17,800 miles/hour). The energy would have to be stored near the Star Tram launch system, potentially using Superconducting Magnetic Energy Storage. The launch vehicle travels through the entire acceleration tube in only 5.3 minutes.

The launch tube is magnetically levitated by the repulsive forces between SC cables attached to the tube and SC cables on the ground beneath it. A current of 14 mega amps in the levitated cables and an oppositely directed current of 280 mega amps in the ground cables produces a repulsive force of 4 tonnes/m at an altitude of 72,000 feet above sea level. The launch tube is stabilized against the net upward magnetic force and wind forces by an array of high-strength tethers that are anchored to the ground. The exit end of the launch tube prevents entry of the external atmosphere (at 72,000 ft.) and allows the vehicle to exit. Several options to accomplish this task are being evaluated. Retractable diaphragms and thin-film-burst diaphragms are being considered, although the leading candidate is a gas dynamic- ejector system. The launch vehicle travels through the 174-mile-long launch tube in 0.58 minutes.

The Star Tram launch system uses two basic types of launch vehicles. One is a reusable launch vehicle (RLV) capable of carrying people and cargo to orbit. The other is an unmanned Hybrid Logistics Module (HLM) for one-way-to-orbit cargo transport (see Figure 4). Both vehicles would carry lightweight SC magnets that inductively react with a guideway of simple aluminum loops at ambient temperature to levitate the moving vehicle inside the launch tube. A separate AC current winding in the guideway pushes on the onboard SC magnets, accelerating the vehicle.

The RLV would have a gross weight of about 200 metric tonnes with a 70-metric-tonne payload capacity. The RLV dimensions are 5 m x 5 m x 40 m (16.5 ft. x 16.5 ft. x 130 ft.). The HLM would have roughly the same dimensions. The HLM could transport cargo ranging from satellites to supplies for a space station.

Figure 4

Star Tram Launch Vehicles

RLV

HLM
(Shown Without Fairings)

The RLV would return to earth like the Space Shuttle and land on a horizontal runway. A vertical-landing RLV may also be developed that would land under power in a vertical configuration on a pad landing facility. The HLM is launched through the Star Tram launch tube in the same manner as the RLV, but does not return to Earth.

The potential benefits of the Star-Tram concept towards making access to space more routine and affordable include:

1. Star-Tram shifts most all the energy requirement for achieving orbit to a robust ground infrastructure. In this sense, Star-Tram is Maglifter taken to the extreme with all the velocity and acceleration of the vehicle being imparted by the ground systems.

2. The level of the engineering endeavor, though seemingly daunting, is actually in line with many complex, large, civil-engineering works such as the Chunnel connecting Western Europe and The United Kingdom, the building of large and extensive, metropolitan underground railway systems or mobile oil-drilling platforms.

Spaceport Implications of the MagLifter Concept

REQUIREMENTS

Following are requirements and considerations included in developing a conceptual flow diagram and facilities plan for the MagLifter Spaceport launch facilities.

Maglifter requires a fixed guideway length of approximately 2.6 miles. Add to this length the required safety separation between the fueling position at the start of the guideway and the remaining support facilities and the overall guideway length exceeds 3 miles. Topography should be as flat as possible. The Earth orbits to be served require a west-to-east guideway orientation. For reasons related to safety and noise exposure the launch end of the guideway should be oriented toward unpopulated, open areas and should be bare of trees to reduce the risk of fires resulting from operations or launch mishaps.

The complex will require at least one runway landing facility approximately 3 miles long to serve the Argus flight vehicle and to accommodate the shipping and receiving of flight vehicles and payloads, as well as support, supply and emergency aircraft. Orientations that meet prevailing and crosswind configurations would be ideal.

Accessibility to and from the site by multiple modes of transportation will be necessary. In addition to transport via air, the primary means of shipping flight vehicles, payloads and large quantities of fuels to and from the site will be via rail. Access to a major rail line via a spur route to the site is required. Highway access is also important for shipping and receiving equipment, as well as for access by passengers, crew and facility workers. Access to major state, federal and interstate highways should ideally be available within 10 miles of the site.

As currently planned, MagLifter will require significant electrical power for levitation and propulsion, more than can be drawn from the power grid. Therefore, plans call for a power generation and storage facility on-site. The Argus flight vehicle as presently envisioned also requires large amounts of fuels. The plan, therefore, assumes the generation facility will include a co-generation plant with related fuel storage facilities and delivery systems.

It is necessary to separate the launch complex from fuel manufacturing or storage facilities, other spaceport facilities and adjacent communities. The selected site must have enough open space to allow safety separations to be maintained.

Access to the eastern range is essential to launch operations. Range launch capacity and reset period will need to be evaluated and enhanced as frequency of launches increases to one per day or more. Air traffic interference with vehicles returning from orbit is not expected to be an issue.

GROUND FLOW ANALYSIS

A ground flow analysis was conducted and a ground flow diagram developed to identify and graphically represent the relationships between the operations required to prepare, launch, recover and service an Argus-type flight vehicle and related launch-assist components. The diagram was prepared based upon the following assumptions about the Argus vehicle and required supporting services. While Argus is primarily configured as a non-crewed cargo vehicle, passenger and crewed flights are possible; therefore, facilities for crew and passengers will be included. While on the ground, Argus will be towed on its gear from recovery to service facilities until it is integrated with a sled for launch. Please refer to Exhibit I, to review the MagLifter Ground Flow Diagram.

Using color coding, the diagram depicts major events from the time Argus lands and arrives at the recovery facility until it is launched on its next mission. Events are divided into two categories: in-line operations (green-colored events), which define the critical path activities required for each flight to maintain the shortest possible turn-around time between flights, and off-line operations (all other colors), which are activities performed in support of online activities, but are not flight-specific and may be accomplished over a longer period of time without directly affecting critical-path flight schedules.

In-line operations begin with the flight vehicle arriving at the landing facility and taxiing to the landing and recovery area where post-flight safing procedures occur and passengers and crew are off-loaded. Next, the vehicle moves to the payload removal bay for removal of payload containers to the isolation and decontamination area. The vehicle then moves to the vehicle processing and service bay, where systems performance is verified and routine maintenance operations are performed. The vehicle then moves to the integration bay where payload containers are inserted and tested and the vehicle is mated to the launch sled. The sled and vehicle move along the guideway from the service facility to the pre-launch area for fueling, loading of flight services supplies and the boarding of passengers and crew (when applicable). At this point the sled and vehicle move to launch position in the launch systems bay; final pre-launch checks are completed and launch is initiated.

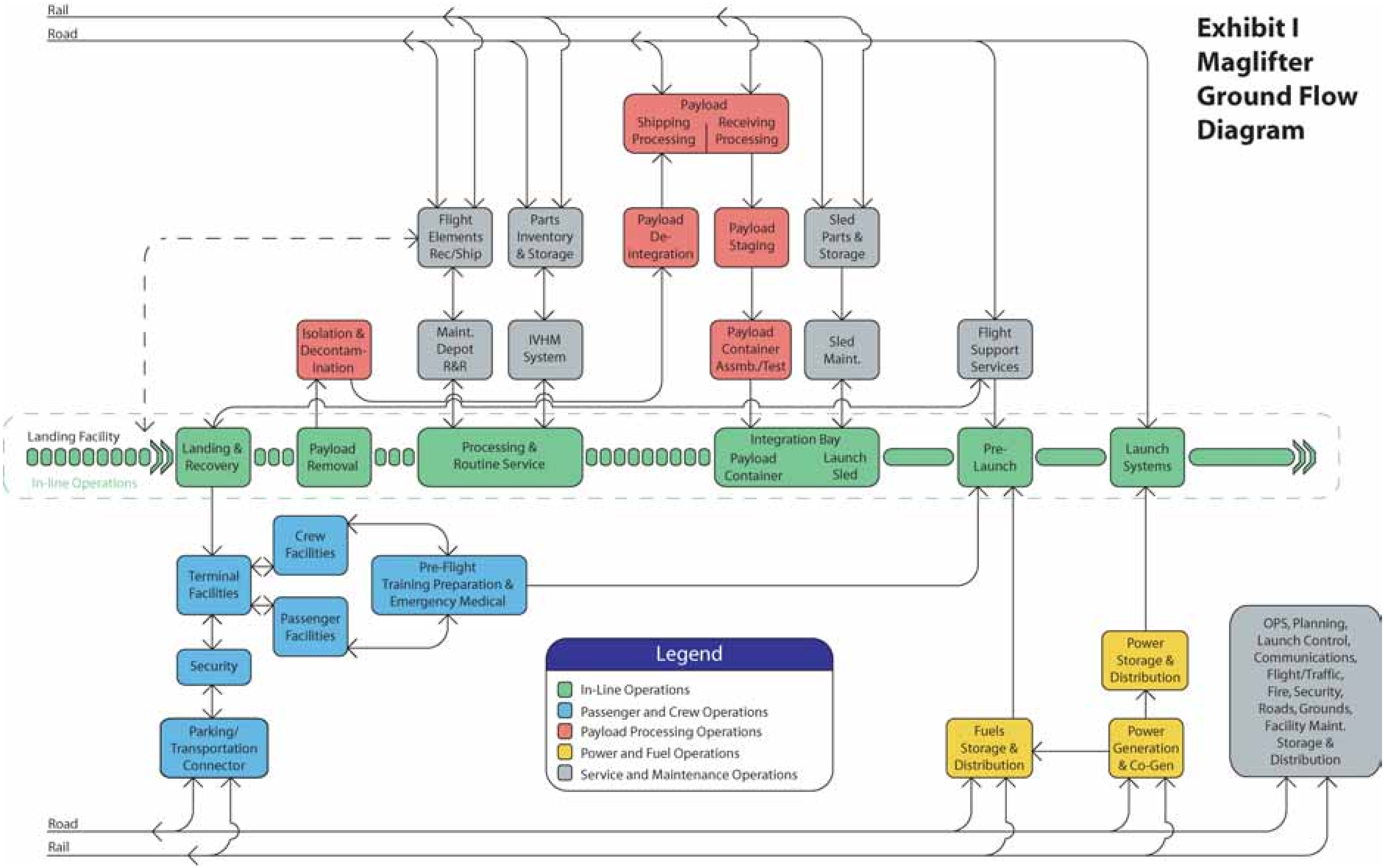
The following off-line operations include services required in support of in-line operations.

Passenger and crew facilities (color-coded blue) include facilities necessary to transfer passengers and crew to and from the flight vehicle. Supporting services include: parking, check-in, security, food service and lodging, medical services, pre-flight training, flight preparation and post flight check-out, passenger/crew holding areas and transfer system.

Payload processing facilities (color-coded red) are all areas required to receive, handle, load, unload and ship payloads to be delivered to (up payloads) and returned from (down payloads) space. It is assumed that payload delivery to space will be accomplished on an in-time basis, meaning payload development and testing will be accomplished at facilities away from the spaceport launch complex, and only final integration into standard payload containers and check-out will be accomplished on-site. A central receiving and shipping facility will handle all payloads arriving for launch or returning from space. From receiving, up payloads may be staged in a storage area or moved directly to the payload container assembly and test area, where payloads are integrated into standard payload containers and tested prior to installation into the launch vehicle in the payload container integration and test bay. Upon return from space, containers are removed from the flight vehicle in the payload container removal bay and transferred to the isolation and decontamination area. Then the containers are moved to the payload de-integration area, where payloads are removed from containers and prepared for shipping off-site via the shipping facility.

Service and maintenance facilities (color-coded gray) include flight vehicle and launch-assist system maintenance facilities, flight operations, and facility-support services. Vehicle maintenance facilities will provide all required maintenance that cannot be accomplished in-line due to time constraints. They include such procedures as scheduled overhaul and engine repair or replacement. The vehicle maintenance area will include facilities to receive, inventory and supply parts to service and maintenance areas via the Integrated Vehicle Health Management system. They will also receive and checkout new flight vehicles prior to placement in-line. Launch-assist system maintenance facilities include areas to transfer sleds off-line for service and repair, together with facilities and equipment to maintain and repair the guideway. Flight-support services facilities provide consumables for passenger/crewed flights and would be delivered to the flight vehicle at pre-launch and removed at landing/recovery. Flight-support services facilities could be located either on-site or remote from the launch complex. Flight operations encompass all functions required to control the spaceport facility including facility management, flight control and

Exhibit I
Maglifter Ground Flow Diagram



Legend

- 🟩 In-Line Operations
- 🟦 Passenger and Crew Operations
- 🟥 Payload Processing Operations
- 🟨 Power and Fuel Operations
- ⬜ Service and Maintenance Operations

planning, communications, security, and emergency services. Facility-support services include buildings, operations and equipment necessary to maintain the Spaceport.

Utility and fuel facilities (color-coded yellow) include the power generation and fuel production facilities located adjacent the launch complex. Fuel storage and co-generation facilities will supply fuel to the pre-launch area via underground piping. The power generation and storage complex will supply power to the launch-assist facilities via an underground distribution system.

CONCEPTUAL APPLICATION

The MagLifter conceptual plan is based upon the assumption that the complex will be located at Kennedy Space Center, in the location proposed by the Cape Canaveral Spaceport Master Plan for the north horizontal launch complex. The Master Plan provides for the placement of a horizontal launch facility in a west-to-east orientation with the launch overflight area located over the Atlantic Ocean, thereby providing the appropriate safety operating area. The north launch complex is located adjacent to the existing Shuttle Landing Facility (SLF), which could accommodate vehicle landing requirements for the MagLifter/Argus program and supporting aviation activity. Because the SLF is not located immediately adjacent to the proposed launch complex and service facilities, and to provide for a crosswind alternative to the SLF, construction of a second runway is suggested. The area allocated in the master plan for the horizontal launch facility is wide enough for the construction of a parallel landing facility/runway adjacent to the launch guideway.

The overall arrangement and separation of facilities within the complex and on-site is due to safety separation requirements related to the quantities and types of fuel proposed for the Argus flight vehicle. There are three major building facilities that compose the MagLifter launch complex: the flight vehicle service facility, the launch facility, and the terminal facility. The launch facility, where fueling is accomplished, is separated from the flight vehicle servicing facility by approximately one half mile, with the two facilities connected by the service guideway, (an extension of the launch guideway used to move the mated sled and flight vehicle from the service facility to launch position). The terminal facility, which contains all passenger, crew and administrative operations, is separated from both the vehicle service and launch facilities by approximately one half mile and is connected to both by a MagLev people mover system. Additional facilities located on site include the flight control tower and launch control facilities, the power generation and fuel production complex and the launch support and technical development complex. Because it is assumed that this complex is located at KSC, many support services that would otherwise be required are already in place at KSC and are not duplicated for the MagLifter complex. Following is a more detailed description of the major elements of the conceptual MagLifter complex.

Flight vehicle service facility

The flight vehicle service facility is the center of operations for post-flight vehicle service and pre-flight vehicle preparation. The facility is envisioned to function much like a manufacturing facility assembly line, wherein the flight vehicle progresses from service bay to bay as "in-line" operations are performed to accomplish the fastest possible turnaround time from vehicle recovery to next launch. In-line bays, beginning with vehicle return from orbit, include: passenger/crew recovery and vehicle safing, payload removal, routine vehicle processing and service, launch sled and payload container integration, pre-launch, and launch. Each in-line bay is supported by "off-line" facilities that perform operations related to the in-line bay, but require more time to accomplish or are not on the same schedule. For example, launching one vehicle per day would require integrating one payload container each day. However, it may take several days to prepare a payload container for launch. For the in-line container integration bay to meet the one-per-day schedule, it is necessary to have an off-line facility that can prepare multiple payload containers so that there will be one ready for integration each day. Following is a brief description of each in-line bay and the related supporting off-line facilities.

Recovery and vehicle safing: The recovery bay is an exterior space to which the flight vehicle will taxi or be towed upon landing. The area will function much as a gate position at an airport, with a loading bridge to off-load passengers and crew (if any), and a ground crew to check and inspect the vehicle prior to moving it into the service facility. After being cleared to enter the service facility, the vehicle is towed to the payload removal bay.

Payload removal: Modular payload containers will be removed from the vehicle by overhead handling devices. All payload-specific vehicle-to-container support equipment and umbilicals will also be removed. The payload container will be moved to an adjacent area where it will be examined and may be isolated and/or decontaminated if necessary. After clearance by the removal facility, the container is transferred to the de-integration facility. Upon completion of container removal, the vehicle is towed to the service bay.

Processing and service: Routine maintenance and systems checks are performed in the processing and service bay where turnaround can be accomplished in a few hours. For extensive procedures requiring more time than that allowed for in-line schedules, vehicles are towed off-line to an adjacent maintenance area with bays dedicated to heavy maintenance, overhaul, and component replacement. There is also a bay for receiving and check-out of new flight vehicles prior to being placed in service. A parts receiving, storage and distribution area is adjacent to both service and maintenance. The service, maintenance and parts areas are interconnected to an Integrated Vehicle Health Management (IVHM) system. As envisioned, the automated system is integral to the flight vehicle and connected to a service facility network that can detect and report vehicle service and maintenance issues and schedule needed repairs and procedures. The system will also requisition the needed parts for delivery to the appropriate service location, maintain an inventory of parts and supplies, and re-order inventory as necessary.

Sled and Container Integration: Upon completion of servicing, the flight vehicle is towed to the payload container and launch sled integration bay. It is envisioned that all payloads will be delivered to space in modular containers. The integration bay is where loaded containers are placed in the flight vehicle, support connections made and systems checked on a quick-turn basis. An extensive off-line payload facility is envisioned for handling up and down payloads. Up payloads shipped to the site via truck, rail or air will be received in ready-to-launch configurations, with payload development and testing accomplished off-site prior to delivery. After check-in, up payloads will be moved to a holding area or immediately to the payload/container integration lab, depending upon launch schedule. The lab is sized to handle integration and testing of multiple payload/container assemblies at one time to meet in-line launch schedules. Down payloads are moved to a de-integration lab from the removal bay to be separated from the container, prepared for shipping and moved to the shipping and receiving area for shipping via truck, rail or air. After integration of the payload container, the flight vehicle is mated to the launch sled. The sled is envisioned as being very robust and will require only occasional maintenance. When required, an adjacent maintenance area and laterally moving section of guideway will facilitate switching of sleds for off-line service. The maintenance area will serve both sled and guideway maintenance functions and will include parts inventory and a shipping/receiving area for sled parts and components. After the vehicle is mated to the sled, the sled leaves the flight vehicle service facility and moves on the guideway to the launch facility, approximate one half mile away.

Launch Facility

The launch facility includes pre-launch and launch operations. Pre-launch operations include vehicle fueling, on-loading food and other perishable items, and boarding passengers and crew. Fuel is supplied to the vehicle via an automated umbilical and the underground piping network from the fuel storage facility. On-board food and related materials are prepared at a support services facility adjacent to the complex and are delivered to the pre-launch facility. Passengers and crew arrive just prior to launch via the MagLev people mover from the terminal facility. The launch facility is envisioned to enclose the end of the launch guideway and be the point from which the levitated sled begins its acceleration to launch. As such, it would also contain control and monitoring facilities related to launch.

Terminal Facility

Terminal facilities include accommodations for limited numbers of passengers and flight crew similar to those found in a commercial airport, including parking, arrival lobbies with check-in stations, security screening, holdroom areas, and overnight accommodations with food service and entertainment. Facilities will also include areas to train and prepare passengers and crew for space flight, as well as medical facilities for evaluation, flight readiness assessment and emergency treatment. Also located in the terminal are administrative offices for launch planning and operations. The terminal includes a MagLev transporter station and will be connected to the vehicle service and launch facilities by an elevated transporter guideway system that will move passengers and crew between the terminal and arriving and departing spacecraft.

Power Generation and Fuel Production & Storage Facility

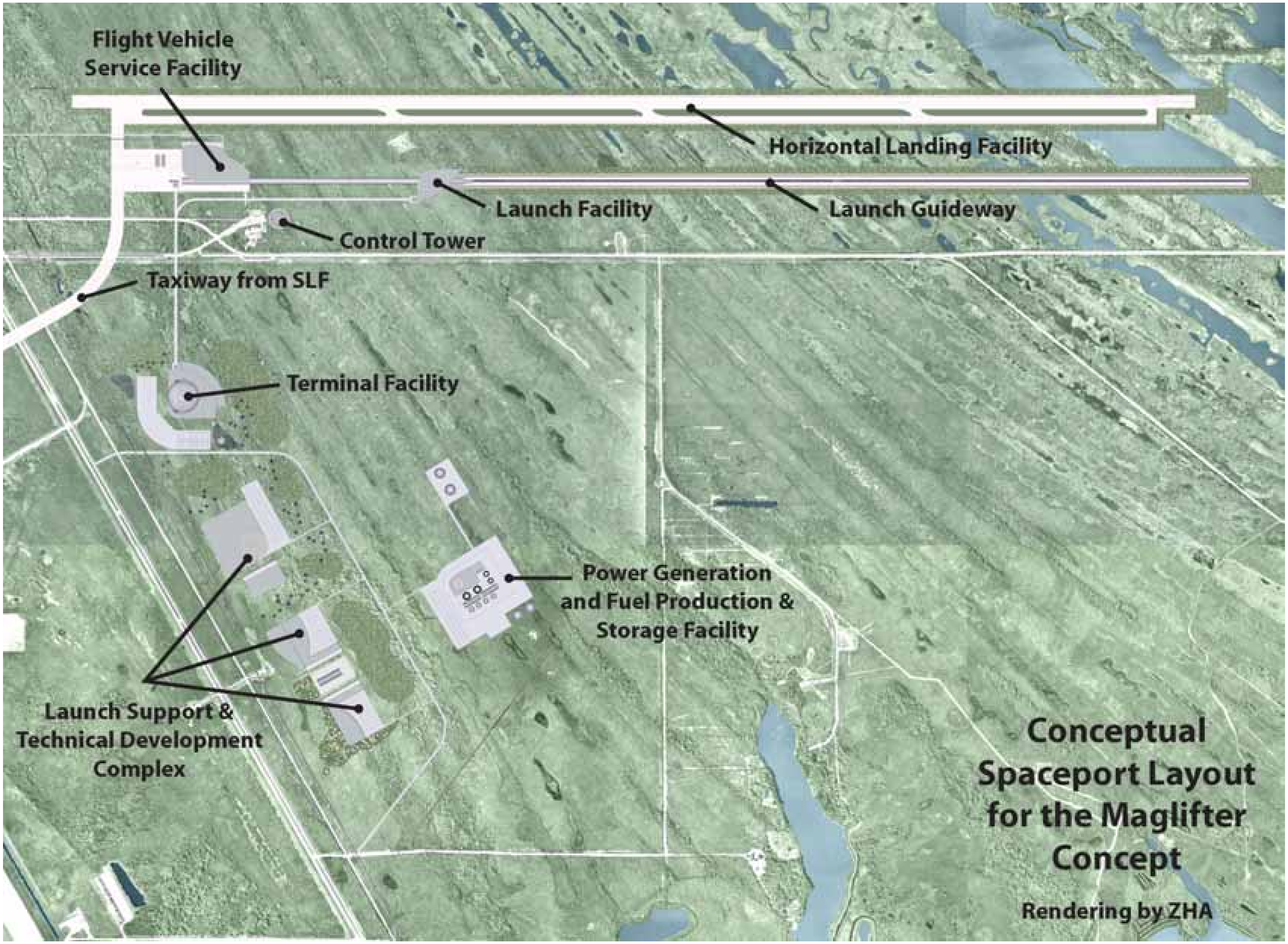
The power generation facility is located adjacent to the launch support and technical development complex in a location reserved for launch support facilities. Because the magnetic levitation and launch propulsion systems have power requirements far exceeding capacities available from the existing power grid, a separate stand-alone power generation and storage facility with co-generation capabilities to manufacture and store fuels is planned. Separation between the plant and adjacent facilities is provided to accommodate the process of manufacturing and storing large quantities of fuels required for the Argus vehicle.

Launch Support and Technical Development Complex

The launch support and technical development complex is an area set aside in the master plan for facilities that support launch operations, launch vehicles and payloads, but do not need to be located at the launch complex. Facilities located in this area might be similar in function to, or extensions of, those located in the KSC International Space Research Park (ISRP), whose functions include research and payload development. Facilities in this area might also assemble and test payloads prior to transfer to the integration lab at the launch complex and conduct experimental development and testing of flight vehicles and support systems.

MAGLIFTER RENDERINGS

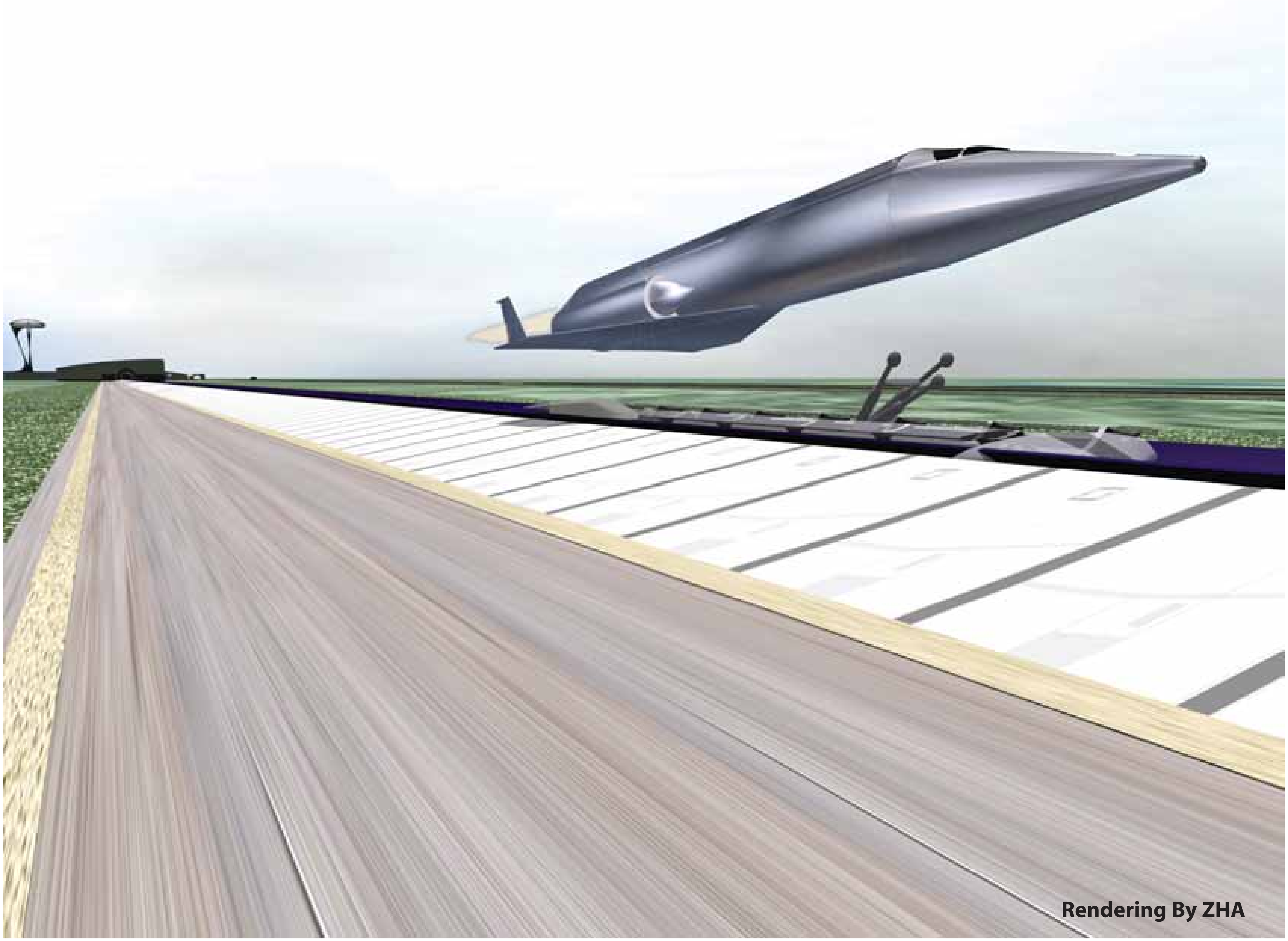
The following three renderings (pages 10,11 and 12) provide a conceptual visualization of the MagLifter launch system and related spaceport facilities at the Kennedy Space Center.



Conceptual Spaceport Layout for the Maglifter Concept

Rendering by ZHA


Rendering By ZHA



Rendering By ZHA

Spaceport Implications of the StarTram Concept

REQUIREMENTS

The large scale of the Star Tram concept demands a location that is relatively flat, seismically stable and without geographic hurdles, such as mountains and deep canyons. While these geographic hurdles could be overcome by constructing tunnels and bridges, there would be cost implications. The launch tube would be oriented west to east to take advantage of the earth's rotation in accelerating a launch vehicle to orbital velocity. The levitated portion of the launch tube is subject to wind forces. Locations with high wind, lightning and tropical storm activity would be avoided. The Kennedy Space Center, while it is the preeminent U.S. launch facility, is not large enough to contain the 969-mile-long Star Tram launch system.

The Star Tram concept poses a risk to air traffic from the point the launch tube begins to climb from the earth's surface to a point 136 miles down range where the launch tube ends. The launch tube and its restraining tethers form a spider- like web 72,000-feet high and 136-miles long. For this reason, the Star Tram levitated launch tube would not likely be located anywhere near existing air traffic routes or major airports. The Spaceport, located at the start of the Star Tram acceleration tube, is more than 800 miles away and air operations there are not impacted by the Star Tram levitated launch tube and restraining tether system.

The magnetic levitation and acceleration systems used by Star Tram require very large amounts of electrical energy. The acceleration driver alone requires 20GW of power be delivered within a few minutes to accelerate the launch vehicle to orbital speeds. The energy most certainly would be generated and stored on or very near the Spaceport. Distributed Superconducting Magnetic Energy Storage (DSMES) is one promising concept to store electrical energy. DSMES has virtually instantaneous response and nearly loss-free storage of energy, with low environmental impact. If the energy storage system is distributed along the launch tube, energy losses associated with a long distribution bus are minimized. Pump stations and refrigeration stations will be located at intervals along the 969-mile Star Tram launch system. The pump stations are necessary to lower the air pressure in the launch tube and the refrigeration units are required to keep the superconducting materials at the proper temperature. The power to operate these facilities will have to be distributed to the sites from sources along the length of the 969-mile Star Tram launch system.

While some of the Star Tram requirements suggest a remote location, a nearby community for basic services for facility staff and visitors is essential. Residential, commercial, recreation, education and health care are some of the services required. A thriving community with all necessary services is required to attract and retain top talent for the Spaceport. The community may also share water, sewer and other utility services with the Spaceport.

The Spaceport will require connections to the surrounding transportation infrastructure. Road, rail and air services will be needed to efficiently transport the launch vehicle components, payloads, spaceport employees and visitors, launch vehicle crew and passengers to the spaceport.

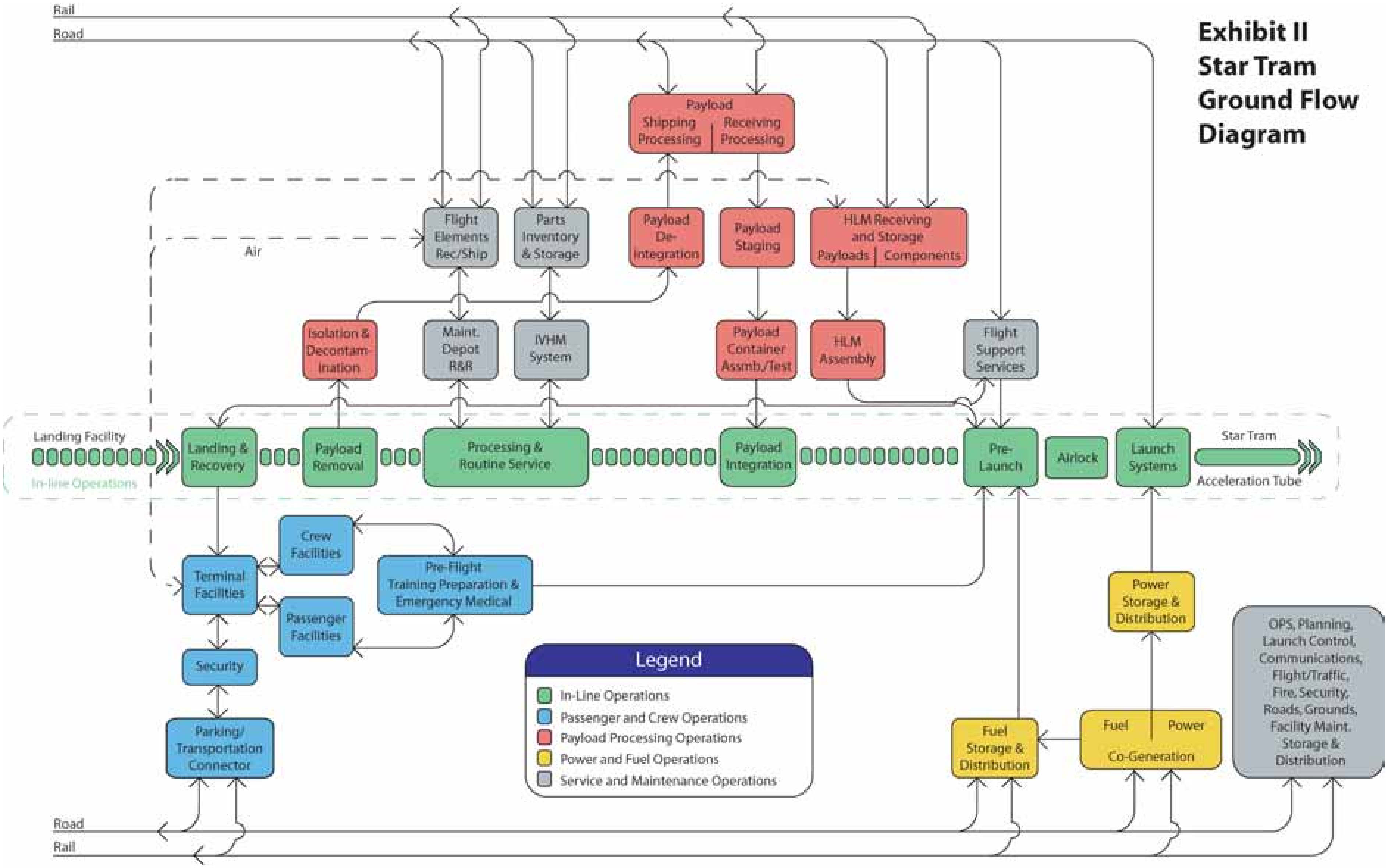
While the above-listed Star Tram requirements have been identified, determining actual site alternatives satisfying these requirements was not a part of this study.

GROUND FLOW ANALYSIS

A ground flow analysis was conducted and a ground flow diagram developed to identify and graphically represent the relationships between operations required to prepare, launch, recover and service Star Tram Reusable Launch Vehicles (RLV). Star Tram is capable of launching both RLVs and non-reusable cargo-only vehicles called Hybrid Logistics Modules (HLM). The ground flow diagram was prepared based upon the following assumptions about the RLV and required supporting services. The RLV could be configured as a crewed cargo vehicle and a crewed passenger vehicle. Therefore, facilities for crew, passengers and cargo will be included. While on the ground, the RLV will be towed on its landing gear from recovery to service facilities and until it is loaded into the launch tube via an airlock. Please refer to Exhibit II, to review the Star Tram Ground Flow Diagram.

Using color-coding, the diagram depicts major events from the time the RLV lands and arrives at the recovery facility until it is launched on its next mission. Events are

Exhibit II
Star Tram Ground Flow Diagram



Rail
Road
Payload Shipping Processing | Receiving Processing
Air
Flight Elements Rec/Ship
Parts Inventory & Storage
Payload De-integration
Payload Staging
HLM Receiving and Storage
Payloads | Components
Isolation & Decontamination
Maint. Depot R&R
IVHM System
Payload Container Assmb./Test
HLM Assembly
Flight Support Services
Landing Facility
In-line Operations
Landing & Recovery
Payload Removal
Processing & Routine Service
Payload Integration
Pre-Launch
Airlock
Launch Systems
Star Tram
Acceleration Tube
Crew Facilities
Terminal Facilities
Passenger Facilities
Pre-Flight Training Preparation & Emergency Medical
Security
Parking/ Transportation Connector
Power Storage & Distribution
Fuel Storage & Distribution
Fuel | Power
Co-Generation
OPS, Planning, Launch Control, Communications, Flight/Traffic, Fire, Security, Roads, Grounds, Facility Maint. Storage & Distribution
Road
Rail

Legend

- 🟩 In-Line Operations
- 🟦 Passenger and Crew Operations
- 🟥 Payload Processing Operations
- 🟨 Power and Fuel Operations
- ⬜ Service and Maintenance Operations

divided into two categories: in-line operations (green-colored events), which define the critical path activities required for each flight to maintain the shortest possible turnaround time between flights, and off-line operations (all other colors), which are activities performed in support of on-line activities, but are not flight-specific and may be accomplished over a longer period of time without directly affecting critical path flight schedules.

In-line operations begin with the flight vehicle arriving at the landing facility and taxiing to the landing recovery area where post-flight safety procedures occur and passengers and crew disembark. Next the vehicle moves to the payload-removal bay for removal of the payload. The vehicle then moves to the vehicle processing and maintenance bay where on-board systems are checked through the Integrated Vehicle Health Monitoring system and routine maintenance operations are performed. The vehicle then moves to the payload-integration bay where the flight-ready payload containers are inserted and tested. The vehicle moves from payload integration to the pre-launch area for fueling, loading of flight services supplies and the boarding of passengers and crew (when applicable). At this point the vehicle moves to launch position through an airlock at the end of the acceleration tube. Final pre-launch checks are completed and launch is initiated.

At this time it is not known whether the Star Tram RLV will operate as a horizontal or vertical landing vehicle or if vehicles of both types will operate concurrently. The spaceport can be designed to accommodate both horizontal and vertical landing vehicles. Vertical landing RLVs would require vertical landing pads and ground service equipment to off-load passengers and crew and "safe" the vehicle while in the vertical configuration on the landing pad. A moving-gantry-type ground service vehicle would roll up to the vehicle on the landing pad and engage a passenger bridge device for the crew and passengers to disembark. Next the ground service gantry would transition the RLV to a horizontal configuration and set it on a transport vehicle The mobile gantry would then move to a designated location away from the landing pads for storage and maintenance until the next vertical landing operation. The RLV will stay on the transporter until it is ready to be launched again.

The following off-line operations include services required in support of in-line operations:

Passenger and crew facilities, (color-coded blue), include facilities necessary to transfer passengers and crew to and from the flight vehicle and all supporting services. These services include: parking, check-in, security, food service and lodging, medical services, pre-flight training and flight preparation, post-flight check-out, and passenger/crew holding areas and transfer systems.

Payload processing facilities, (color-coded red), encompass all areas required to receive, handle, load, unload and ship payloads to be delivered to (up payloads) and returned from (down payloads) space. It is assumed that payload delivery to space will be accomplished on an in-time basis, meaning payload development and testing will be accomplished at facilities away from the spaceport launch complex, and only final integration into standard payload containers and check-out will be accomplished on-site. A central receiving and shipping facility will handle all payloads arriving for launch or returning from space. From receiving, up payloads may be staged in a storage area or moved directly to the payload container assembly and test area where payloads are integrated into standard payload containers and tested prior to insertion into the launch vehicle. The tested payload container is inserted in the vehicle in the payload integration and test bay. Upon return from space, containers are removed from the flight vehicle in the payload-removal bay and transferred to the isolation and decontamination area. Then the containers move to the payload de-integration area where payloads are removed from containers and prepared for shipping off-site via the shipping facility.

Service and maintenance facilities are color-coded gray and include flight vehicle and launch-assist system maintenance facilities, flight operations and facility-support services. Vehicle maintenance facilities will provide all required maintenance that cannot be accomplished in-line due to time constraints and will support such procedures as scheduled overhaul and engine repair/replacement. The vehicle maintenance area will receive, inventory and supply parts to service and maintenance areas via the Integrated Vehicle Health Monitoring (IVHM) system, as well as receive and checkout new flight vehicles prior to placement in-line. Flight-support services facilities provide consumables for passenger/crewed flights, which would be delivered to the flight vehicle at pre-launch and removed at landing/recovery. Flight support services facilities could be located either on-site or remote from the launch complex. Flight operations comprise all functions required to control the spaceport facility, such as facility management, flight control and planning, communications, security, and emergency services. Facility-support services encompass all buildings, services and infrastructure necessary to maintain the Spaceport.

Power and fuel facilities are color-coded yellow. The power generation and fuel production facilities are located at the Spaceport complex. Power generation facilities will supply fuel to the pre-launch area via underground piping. The power generation and storage complex will supply power to the launch-assist system, as well as the spaceport facilities.

CONCEPTUAL APPLICATION

The conceptual spaceport plan for Star Tram is based upon the assumption that the complex will be located in a very large expanse of relatively flat terrain with a west-to-east orientation of the launch system. Star Tram site alternatives were not evaluated as part of this study. As a result, the analysis and descriptions of the spaceport facilities in this report are not site specific.

There are three major building facilities areas that compose the Star Tram launch complex: the flight vehicle service facility, the launch facility and the terminal facility. Fuel loads on Start Tram launch vehicles are much smaller than the MagLifter concept allowing placement of terminal, launch and service facilities in closer proximity than the MagLifter Spaceport concept. Additional facilities located on-site include the flight control tower and launch control facilities, the power generation/fuel production complex and the launch support and technical development complex

Flight Vehicle Service Facility

The flight vehicle service facility is the center of operations for post-flight vehicle service and pre-flight vehicle preparation. The facility is envisioned to function much like a manufacturing facility assembly line wherein the flight vehicle progresses from service bay to bay as "in-line" operations are performed to accomplish the fastest possible turnaround time from vehicle recovery to next launch. In-line bays include passenger/crew recovery and vehicle safing, payload removal, routine vehicle processing and service, payload container integration, pre-launch and launch. Each in-line bay is supported by "off-line" facilities that perform operations related to the in-line bay, but require more time to accomplish or are not on the same schedule. For example, launching one vehicle per day would require integrating one payload container each day. However, it may take several days to prepare a payload container for launch. For the in-line container integration bay to meet the one-per-day schedule, it is necessary to have an off-line facility that can prepare multiple payload containers so that there will be one ready for integration each day. Following is a brief description of each in-line bay and the related supporting off-line facilities.

Recovery and vehicle safing: The recovery bay is most likely an exterior space to which the flight vehicle will taxi or be towed upon landing. The area will function much as a gate position at an airport, with a loading bridge to off-load passengers (if any) and crew and a ground crew that will check and inspect the vehicle prior to the vehicle entering the service facility. After being cleared to enter the service facility, the vehicle is towed to the payload removal bay.

Payload removal: Payloads in modular containers will be removed from the vehicle with overhead handling devices and any payload-specific vehicle-to-container connections will also be removed. The payload container will be moved to an adjacent area where it will be examined and may be isolated and/or decontaminated if necessary. After the container is cleared by the removal facility, it is transferred to the de-integration facility. Upon completion of payload container removal, the vehicle is towed to the service bay.

Processing and service: Routine maintenance and systems checks are performed in the processing and service bay where turnaround can be accomplished in a few hours. For extensive procedures requiring more time than that allowed for in-line schedules, vehicles are towed off-line to an adjacent maintenance area with bays dedicated to heavy maintenance, overhaul, and component replacement. There is also a bay for receiving and check out of new flight vehicles prior to being placed in service. A parts receiving, storage and distribution area is adjacent to both service and maintenance. The service, maintenance and parts areas are interconnected to an Integrated Vehicle Health Management (IVHM) system. As envisioned, the automated system is integral to the flight vehicle and connected to a service facility network that can detect and report vehicle service and maintenance issues and schedule needed repairs and procedures. The system will also requisition the needed parts for delivery to the appropriate service location, maintain an inventory of parts and supplies, and re-order inventory as necessary.

Container Integration: Upon completion of servicing, the flight vehicle is towed to the payload container integration bay. It is envisioned that all payloads will be delivered to space in modular containers. The integration bay is where loaded containers are placed in the flight vehicle, support connections made and systems checked on a quick-turn basis. An extensive off-line payload facility is envisioned for handling up and down payloads. Up payloads shipped to the site via truck, rail or air will be received in ready-to-launch configurations, with payload development and testing accomplished off-site prior to delivery. After check-in, up payloads will be moved to a holding area or immediately to the payload/container integration lab, depending upon launch schedule. The lab is sized to handle integration and testing of multiple payload/container assemblies at one time to meet in-line launch schedules. Down payloads are moved to a de-integration lab from the removal bay to be separated from the container, prepared for shipping and moved to the shipping and receiving area for shipping via truck, rail or air. After payload integration, the flight vehicle is transported to the launch facility.

HLM Assembly and Integration: The HLM is a disposable cargo-carrying module capable of alternative configurations for delivery of varying types of cargo to space. A separate receiving and integration facility is envisioned to receive, store, handle, assemble and integrate HLM components and payloads. The HLM consists of a cylindrical payload carrying module, two tapered fairings (one applied to each end of the module to make it aerodynamic for launch), and a propulsion pack that is attached to the trailing end of the payload module which fires after the launched module clears the end of the launch tube to assist in the final climb to orbit. All HLM components will be shipped to the service facility by air, rail or truck, and received and stored in the facility, like components in a manufacturing process. As flights are scheduled, HLM's are assembled as they move on the assembly line toward the launch facility. Payloads may be integrated into the HLM module either off-site and shipped to site ready for final vehicle assembly, test and launch, or be shipped to the site and integrated into the module in a process similar to that described for up-payload container loading and integration herein. Once fully assembled with integrated payload, the HLM is transported to the launch facility.

Launch Facility

The launch facility includes pre-launch and launch operations. Pre-launch operations include vehicle fueling, on-loading food and other perishable items, and boarding passengers and crew. On-board food and related materials are prepared at a support services facility adjacent to the complex and are delivered to the pre-launch facility. Passengers and crew arrive just prior to launch from the terminal facility. The launch operations include control and monitoring facilities related to the Star Tram launch system beginning with the airlock.

The entrance to the Star Tram launch system is through a large airlock where the flight ready launch vehicle is placed and the inside pressure is lowered to match that of the evacuated launch tube. Next the vehicle moves from the airlock into the acceleration tube to await launch.

Terminal Facilities

Terminal facilities include accommodations for passengers and flight crew similar to those found in a small commercial airport, including parking and arrival lobbies with check-in stations, security screening, holdroom areas, and overnight accommodations with food service and entertainment. Facilities will also include areas to train and prepare passengers and crew for space flight, as well as medical facilities for evaluation and flight readiness assessment and emergency treatment. Also located in the terminal are administrative offices for launch planning and operations.

Power Generation and Fuel Production & Storage Facility

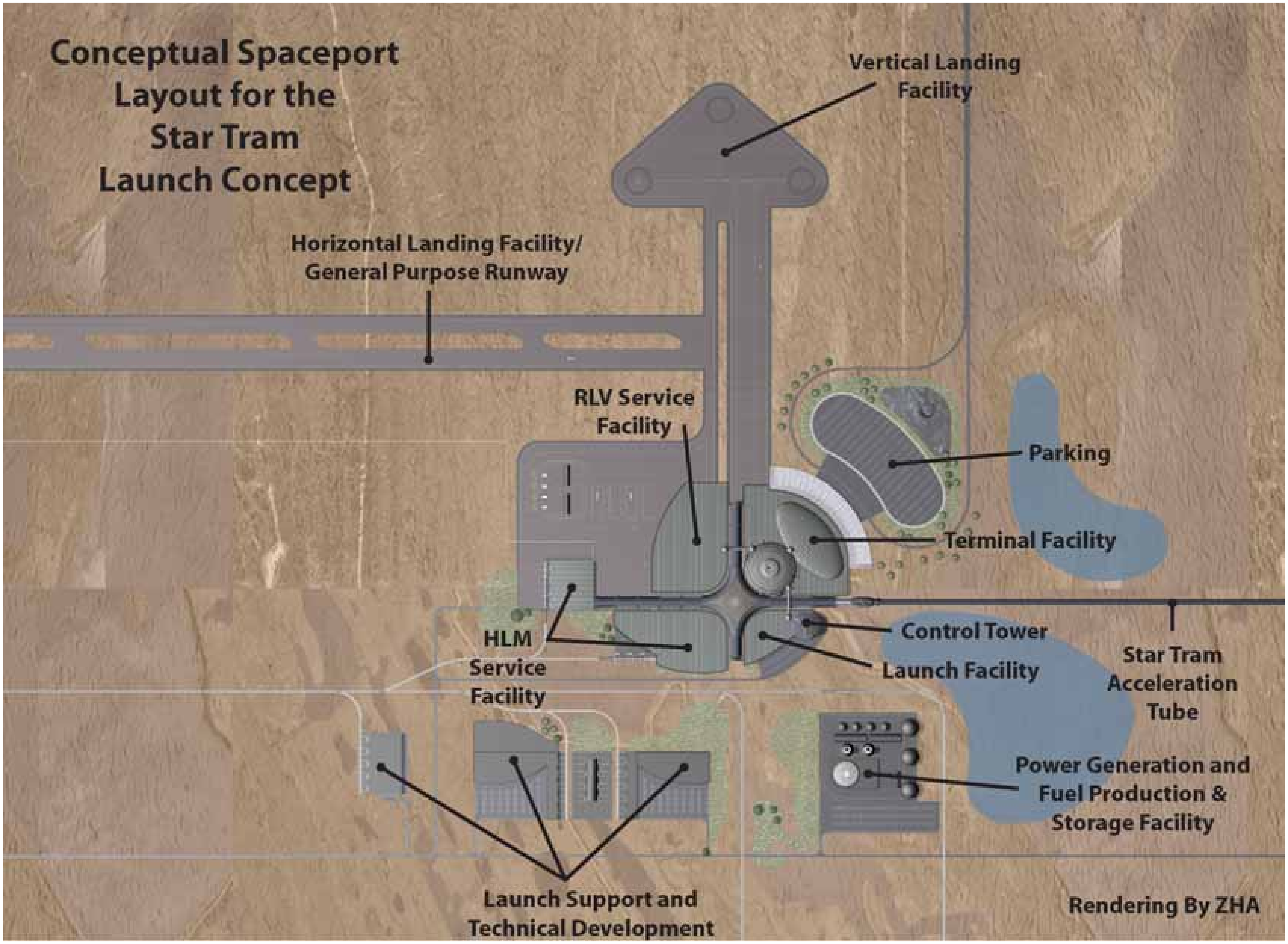
Because the Star Tram magnetic levitation and acceleration systems have power requirements far exceeding capacities available from a typical power grid, a power generation facility is located at the spaceport near the Star Tram acceleration tube. Power is delivered throughout the spaceport through an underground power distribution system.

Launch Support and Technical Development Complex

The launch support and technical development complex is for facilities that support launch operations, launch vehicles and payloads, but do not need to be located at the launch complex. Facilities located in this area would include research and payload development for launch to space. Facilities in this area might also assemble and test payloads prior to transfer to the integration lab at the launch complex and conduct experimental development and testing of flight vehicles and support systems.

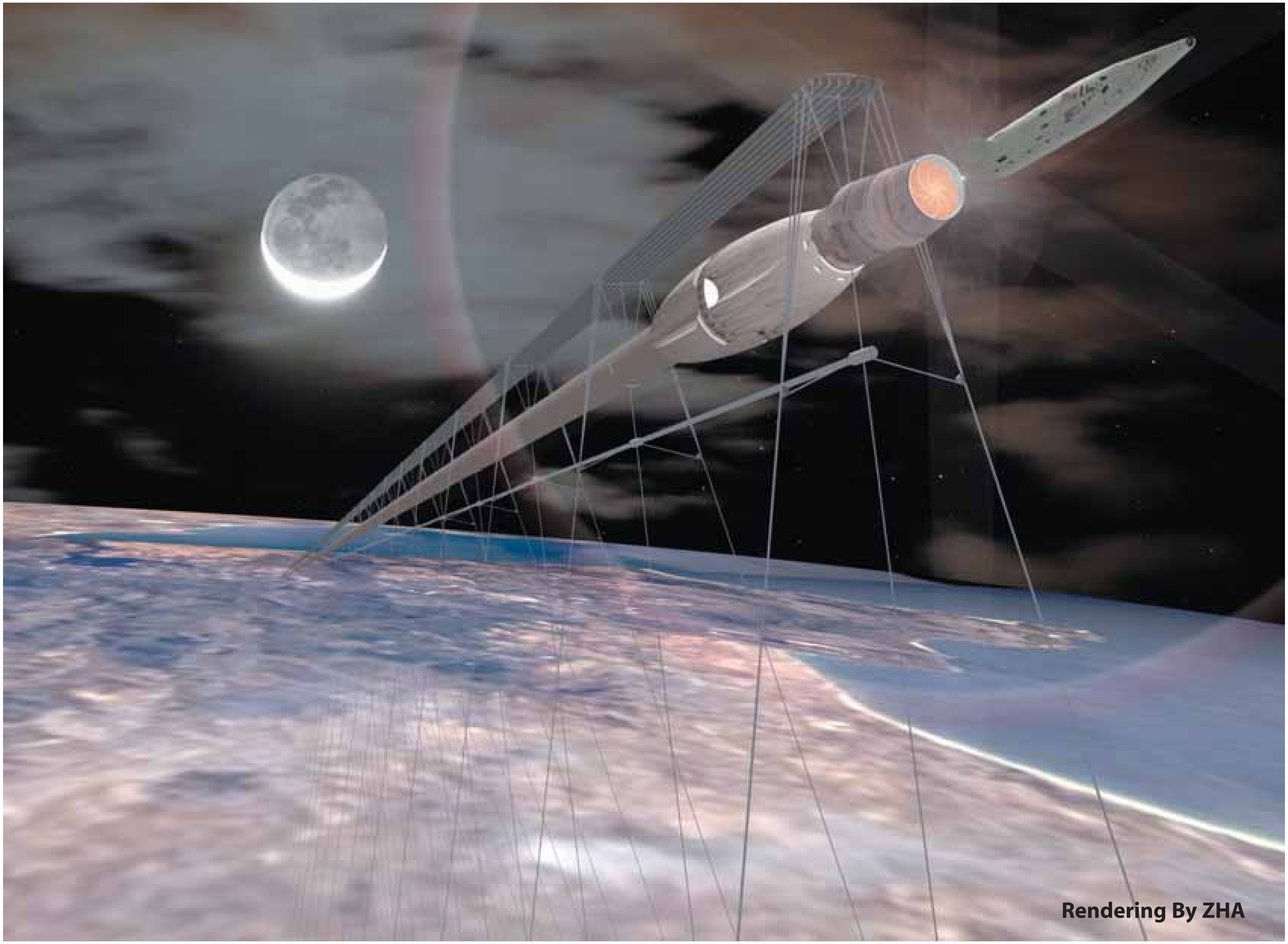
STAR TRAM SPACEPORT RENDERINGS

The following five renderings (pages 19, 20, 21, 22 and 23) provide a conceptual visualization of the Star Tram launch system and related spaceport facilities.


Conceptual Spaceport Layout for the Star Tram Launch Concept
Vertical Landing Facility
Horizontal Landing Facility/ General Purpose Runway
RLV Service Facility
Parking
Terminal Facility
Control Tower
Launch Facility
Star Tram Acceleration Tube
HLM Service Facility
Power Generation and Fuel Production & Storage Facility
Launch Support and Technical Development
Rendering By ZHA


Rendering By ZHA

Rendering By ZHA



Rendering By ZHA


Rendering By ZHA

Summary

MAGLIFTER

The MagLifter launch assist concept is based upon the advancement and combination of existing technologies to create a more efficient means to launch and propel vehicles and payloads to Earth orbit by replacing the flight vehicle first stage with a robust, ground based launch system. Implementation of the concept is expected to result in lower flight vehicle weight, greater payload capacity and lower per-pound-to-orbit launch costs. Advancements in superconducting magnetic levitation and propulsion systems and development of rocket based combined cycle engines will be required before implementation of MagLifter is possible. Improvements in flight vehicle materials and systems reliability/serviceability will be necessary before MagLifter launches become routine. Proponents of the concept believe that required technological advancements are achievable within the time frame targeted by NASA for development of second-generation RLV systems. This study envisions the site characteristics, ground-based facilities, systems and infrastructure necessary to support the proposed launch technology.

MagLifter facility and operations land area requirements allow some flexibility in meeting primary criteria for site location. These criteria include open, level land with sufficient area to accommodate the west-to-east launch facility orientation, landing facilities, adjacent uninhabited launch safety zones and access to the eastern range. The Cape Canaveral Spaceport Master Plan allocates land for a north horizontal launch complex that meets the stated site requirements for MagLifter. The spaceport location also affords other logistical and economic advantages, including: ownership of required land, use of the adjacent Shuttle Landing Facility, access to existing main-line rail and highway transportation systems, utilization of existing spaceport operations, management, maintenance and utility infrastructures, and the availability of a skilled workforce residing in established, supportive, nearby communities.

Timing of technological advancements not withstanding, there are few impediments to hinder the development of a MagLifter complex at the Cape Canaveral Spaceport.

STAR TRAM

The Star Tram launch concept proposes using superconducting magnetic levitation technology to launch payloads to low Earth orbit at a cost less than $100 per pound. Magnetic levitation technology is in use today for high-speed mass transit systems; however, atmospheric drag limits the speed of surface transit systems. The Star Tram evacuated launch tube significantly reduces atmospheric drag on the launch vehicles allowing near orbital speeds. The launch system can recharge and launch again in a few hours. A Star Tram launch system with spaceport facilities supporting both unmanned cargo vehicles and manned RLVs would support very high launch rates.

Unlike the smaller MagLifter launch concept that could be accommodated at Kennedy Space Center, it is clear that the size of the Star Tram launch concept (nearly 1,000 mi. long) significantly limits the number of site alternatives in North America and even the world. The West to East orientation of the launch system and the airspace restrictions required for the elevated launch tube and restraining tether system further reduces the number of site alternatives. Analysis of specific site alternatives was not a component of this study however these significant constraints have been identified. A site appropriate for the Star Tram launch system is likely a remote undeveloped area that would require building all supporting facilities and infrastructure. If an existing developed site is not found to be suitable, the cost of building and operating the made-to-order spaceport for Star Tram is even higher.

Conclusion

Deployment of operational launch-assist systems at a terrestrial spaceport will require overcoming significant challenges. The launch assist systems alone pose technological, construction and cost hurdles. However, no insurmountable challenges from a spaceport prospective have been identified by this study. As with any great achievement, a strategic roadmap to test and prove these launch-assist systems will be needed. The next steps required to develop the technologies and validate cost estimates are outlined in the next section.

Next Steps:

The work outlined in this report offers a macro-level perspective on the challenges associated with space transportation launch-assist concepts in light of future spaceports. Such launch-assist concepts should be developed in greater detail and the potential costs and benefits of such systems more clearly defined. More detailed development and study is required in the following areas to fully define the potential benefits of these systems.

1. Cost estimations of both non-recurring facility and ground support equipment acquisitions, as well as recurring operational costs, are required at a subsystem level.

2. Cost estimation for launch-assist systems requires investments in key technology areas. Without such investments, the potential benefits of these systems will continue to be matters of study without the depth required to increase confidence toward proceeding in this direction for our space transportation architectures.

3. Key spaceport technology areas for development that could significantly enhance the understanding of launch-assist costs and benefits include:

a. Superconducting magnetic levitation and propulsion of sleds and large vehicles

b. Superconducting magnetic levitation of structures

c. Energy storage and distribution systems in the Giga-Watt scale

d. Environmental assessment of the safety and health impacts of magnetic fields

e. Rapid payload integration techniques and approaches consistent with higher flight rates

f. Systems architecture alternatives including flight and ground systems, interfaces, controls and design definition

Technology development should be performed at a scale that is representative and can be analytically scaled to apply to the larger, more extensive systems that might actually be required.

4. Manufacturing techniques and novel designs and approaches require investment in the areas of superconducting magnets and energy storage devices. A well-defined sense of the architectural and engineering implications of launch assist, such as upfront costs and time to implement, would be gained from such efforts.

5. A full study and review of the potential synergies between the developments of these launch assist concepts with other commercial applications should be undertaken. Synergies with rapid mass/commuter transportation systems, miles-long bridge building, high-energy physics, medicine, power-plant energy storage, and storage of energy for the National Electrical Grid, including solar energy storage, should be defined and quantified.

Sources of Data

SUBJECT MATTER EXPERTS:

Rainer Meinke, Advanced Magnet Lab

Dr. John Olds, Georgia Institute of Technology, Department of Aerospace Engineering

Dr. James Powell, Star Tram, Inc.

Edgar Zapata, NASA/KSC Systems Engineering Office

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