The First Mars Outpost: Planning & Concepts

SICSA
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The Sasakawa International Center for Space Architecture (SICSA) is undertaking a multi-year research and design study that is exploring near- and long-term commercial space development opportunities. The central goal of this activity is to conceptualize a scenario of sequential, integrated private enterprise initiatives that can carry Humankind forward to Mars. Each development stage is planned as a building block to provide the economic foundation, technology advancements and operational infrastructure to support others that follow.

This report presents planning considerations and concepts for establishing a first human settlement on Mars. The outpost would support surface missions lasting up to about 500 days, and would constitute the initial stage of larger and continuously operational developments which would make extensive use of Martian resources to minimize reliance upon materials brought from Earth.

Key programmatic assumptions which have guided proposals that are presented in this report are highlighted in a separate SICSA publication titled *Human Mars Initiatives: Issues and Considerations.* That report is the product of an earlier segment of this Mars development study. Both parts of this study were undertaken during the 2001-2002 academic year by students in the SICSA program within the Gerald D. Hines College of Architecture. Participants in this segment of the study include full-time 5th year and graduate students, along with part-time post baccalaureate (PB) students, many of whom are US Space Program professionals employed by NASA and the United Space Alliance (USA). The PBs are candidates to enroll in a proposed Master of Science in Space Architecture program which is being reviewed by the University of Houston, and is expected to be submitted to the Texas Higher Education Coordinating Board for final approval. Collectively, these contributers include the following:

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Study Background and Emphases

A first Mars settlement is part of SICSA's Commercial Space Development Plan.

The Sasakawa International Center for Space Architecture is undertaking a long-term comprehensive space development research, planning, and design program that ultimately envisions human planetary settlements. SICSA's *Commercial Space Development Plan*, which is presented in a separate report, proposes a coordinated sequence of initiatives that constitute important steps for program realization. This scenario commences with small-scale facilities for material processing and other activities in low-Earth orbit (LEO), evolves to support space tourism in LEO, and ultimately creates an economic and technical foundation for planetary exploration and colonization. This report focuses upon requirements, considerations, and concepts for establishing an initial human outpost on the surface of Mars. Future studies and proposals will expand the development and capabilities of this base camp to enable permanent, continuous and increasingly resource-independent operations.

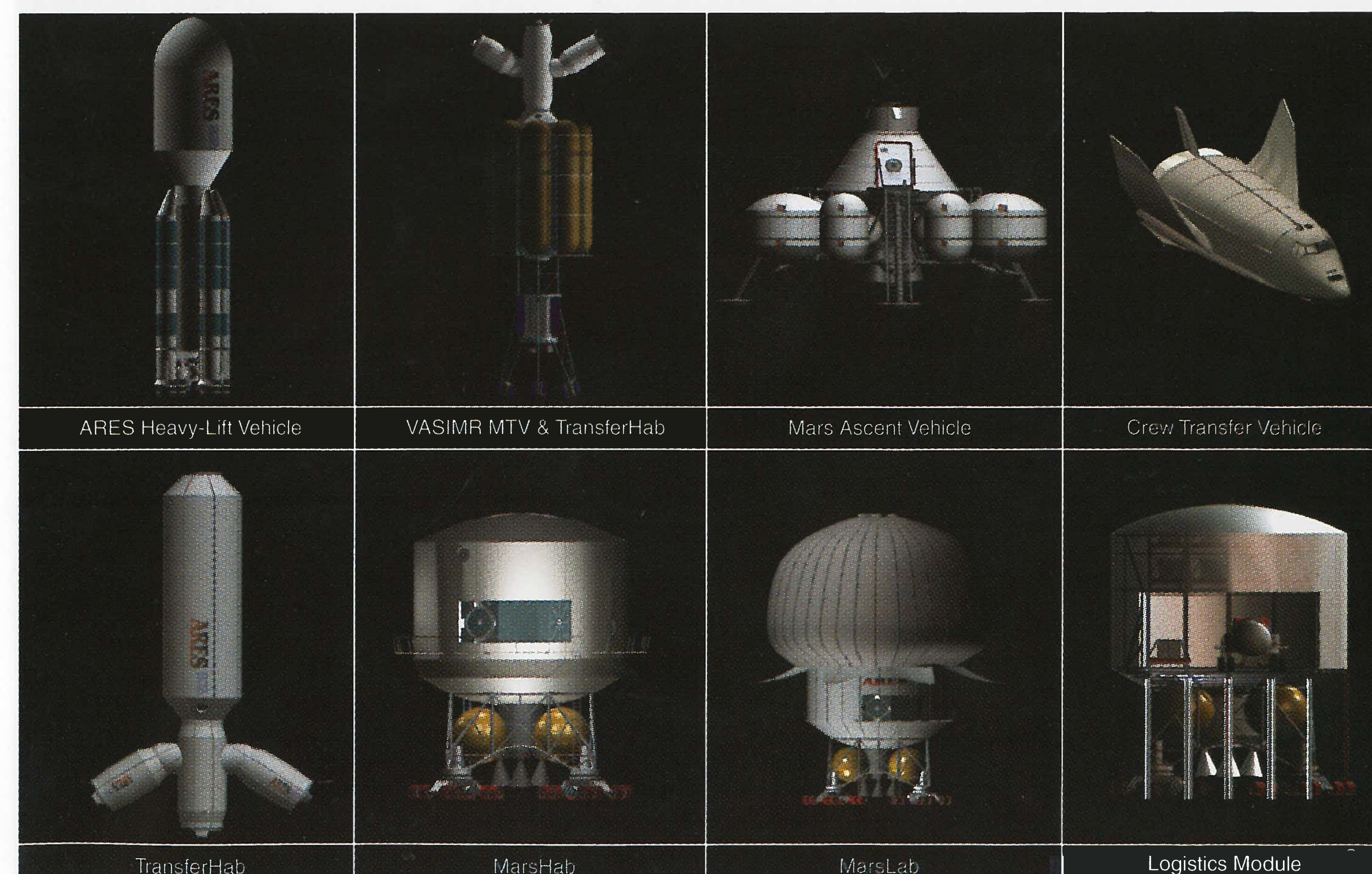
The strategic approach emphasizes private enterprise initiatives aimed at sustainable progress.

SICSA's approach emphasizes sustainable progress through carefully staged achievements guided by long-range plans which are driven by private sector initiatives. The purpose is to be independent of constantly shifting government priorities and unpredictable annual Congressional budget allocations. Unlike the Apollo *sprint missions* which culminated with footprints and flagpoles on the Moon, the goal is to realize a new era of human planetary discovery, habitation and enterprise.

This report proposes planning priorities, design concepts and a staging strategy to establish initial operations on Mars.

Human Mars surface mission planning imposes many essential and challenging program needs. New generations of larger, more advanced launch systems and spacecraft will be necessary to transfer people and large cargo elements from Earth to Mars, land them on the surface, and return crews safely back to Earth. Special habitats will be required to accommodate crews during long voyages to and from Mars, as well as to support them on the surface. This report presents key priorities and design concepts that address these needs.

Key Program Elements.



ARES Heavy-Lift Vehicle | VASIMR MTV & TransferHab | Mars Ascent Vehicle | Crew Transfer Vehicle | TransferHab | MarsHab | MarsLab | Logistics Module

The ARES Heavy-Lift Vehicle

A big heavy-lift vehicle can deliver large elements to LEO and minimize orbital assembly requirements.

The SICSA team has concluded that any economically feasible human Mars program will require the availability of a heavy-lift launch vehicle capable of delivering at least 200 metric ton payloads from Earth to LEO. Previous planning and design activities that baselined the Space Shuttle Orbiter's 25 ton payload capacity would impose a prohibitively large number of launches. Orbiter-size payloads would also necessitate massive facility infrastructure and human operations requirements to assemble and service the numerous and relatively much smaller elements, and would vastly extend the flight readiness and mission turnaround schedules. SICSA's *Artificial Gravity Science and Excursion Vehicle (AGSEV)* proposal which is presented in an earlier report illustrates these disadvantages.

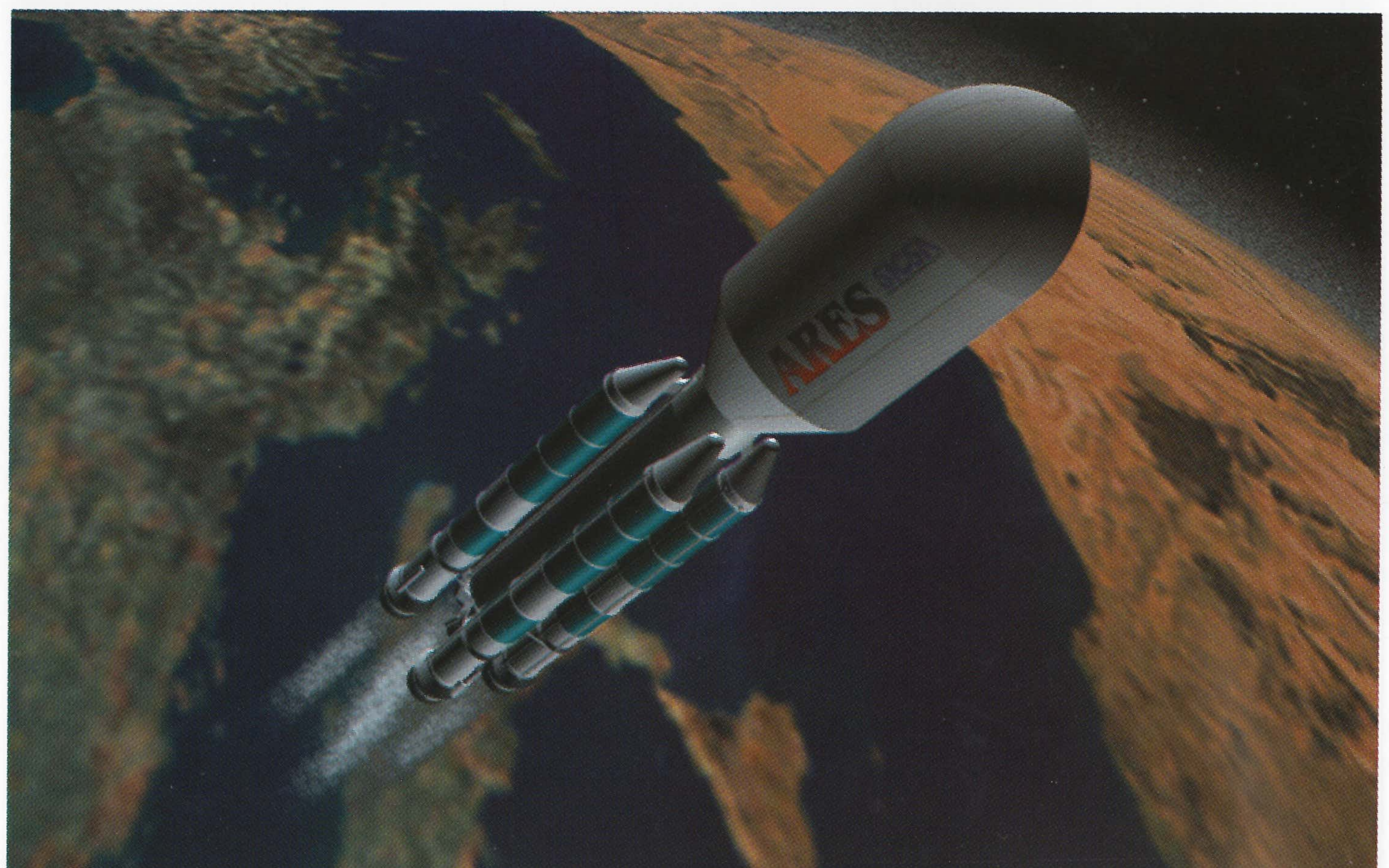
SICSA's proposed ARES booster is scaled to accommodate modules which exceed current launch capabilities.

A large heavy-lift booster can offer a variety of important functional and economic advantages. From a flight operations standpoint, the number of launches will be dramatically reduced. The expanded payload capacity will greatly facilitate operations in LEO, enabling much larger elements to be utilized that can be simply docked together as complete structures rather than assembled in orbit. More generously-sized habitable elements will afford improved crew comfort and functionality, since they can be scaled to provide more optimum interior accommodations which exceed highly restrictive mass and volume limitations associated with current launchers.

Increasing booster size can improve launch efficiency.

Increasing booster size can also improve launch economies by reducing frictional drag that results as a vehicle passes through the Earth's atmosphere. As the vehicle diameter increases, the surface area producing friction increases as the square of that dimension, while the internal volume increases as the diameter's cube. Accordingly, larger boosters have proportionately smaller drag losses relative to volume capacity. ARES is planned to incorporate a 50 ft. diameter payload shroud to accommodate all of the proposed program elements.

Space Shuttle-Derived Proposal Based Upon a Martin Marietta Concept.



Key Payloads Positioned in the ARES 50 ft. Diameter Enclosure.

The VASIMR Mars Transfer Vehicle (MTV)

A proposed variable-thrust engine system would transfer people and cargo between Earth and Mars orbits.

In addition to development of a heavy-lift Earth-to-LEO ARES launch system, a large capacity vehicle will also be needed to transfer habitats, crews, supplies and other items to the vicinity of Mars and back. Unlike the ARES vehicle, this transportation system cannot be created from existing components, nor is it likely to utilize conventional chemical rocket technologies. A much more efficient propulsion source will be necessary to reduce fuel delivery requirements from Earth, and to minimize the mass contribution of the vehicle's fuel to the total mass that must be transferred to Mars and back for each mission.

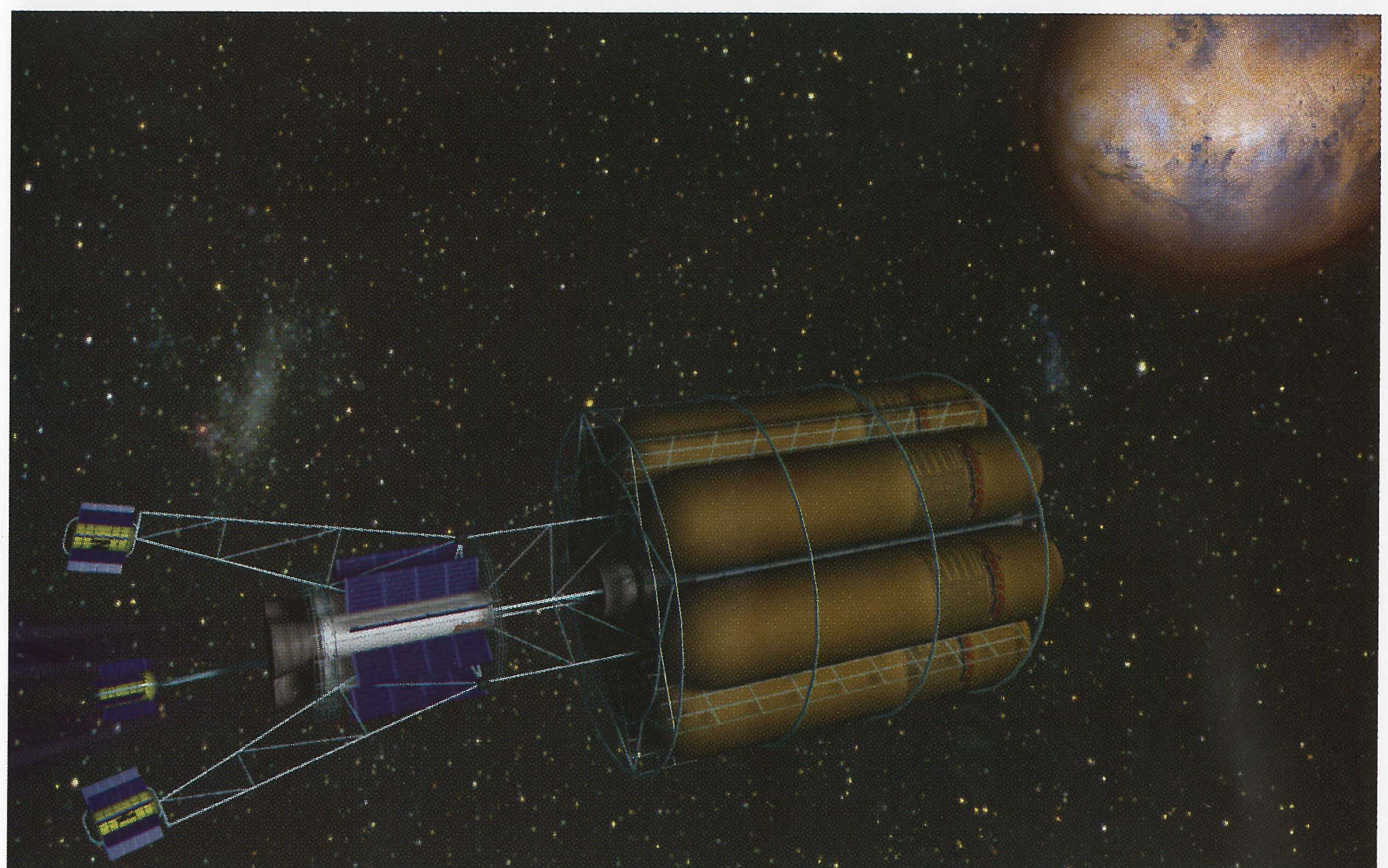
A propellent (usually liquid hydrogen) is ionized by radio waves, heated to high temperatures, and then ejected.

The SICSA team selected a *Variable Specific Impulse Magnetoplasma Rocket (VASIMR)* as the most promising known transfer vehicle propulsion technology. This system makes use of high-energy antennae and magnets to produce and control plasma that is exhausted out of the engine to produce thrust. The amount of thrust released can be varied, enabling the system to accelerate more rapidly when desired, and then throttle down into a more energy-efficient constant lower thrust mode for the remainder of the voyage. The vehicle would continuously accelerate until such time that deceleration is desired. This is accomplished by turning the spacecraft 180 degrees in its orbital vector, causing it to slow its velocity for its approach to the vicinity of Mars on the outbound leg, and again for insertion into Earth orbit upon its return.

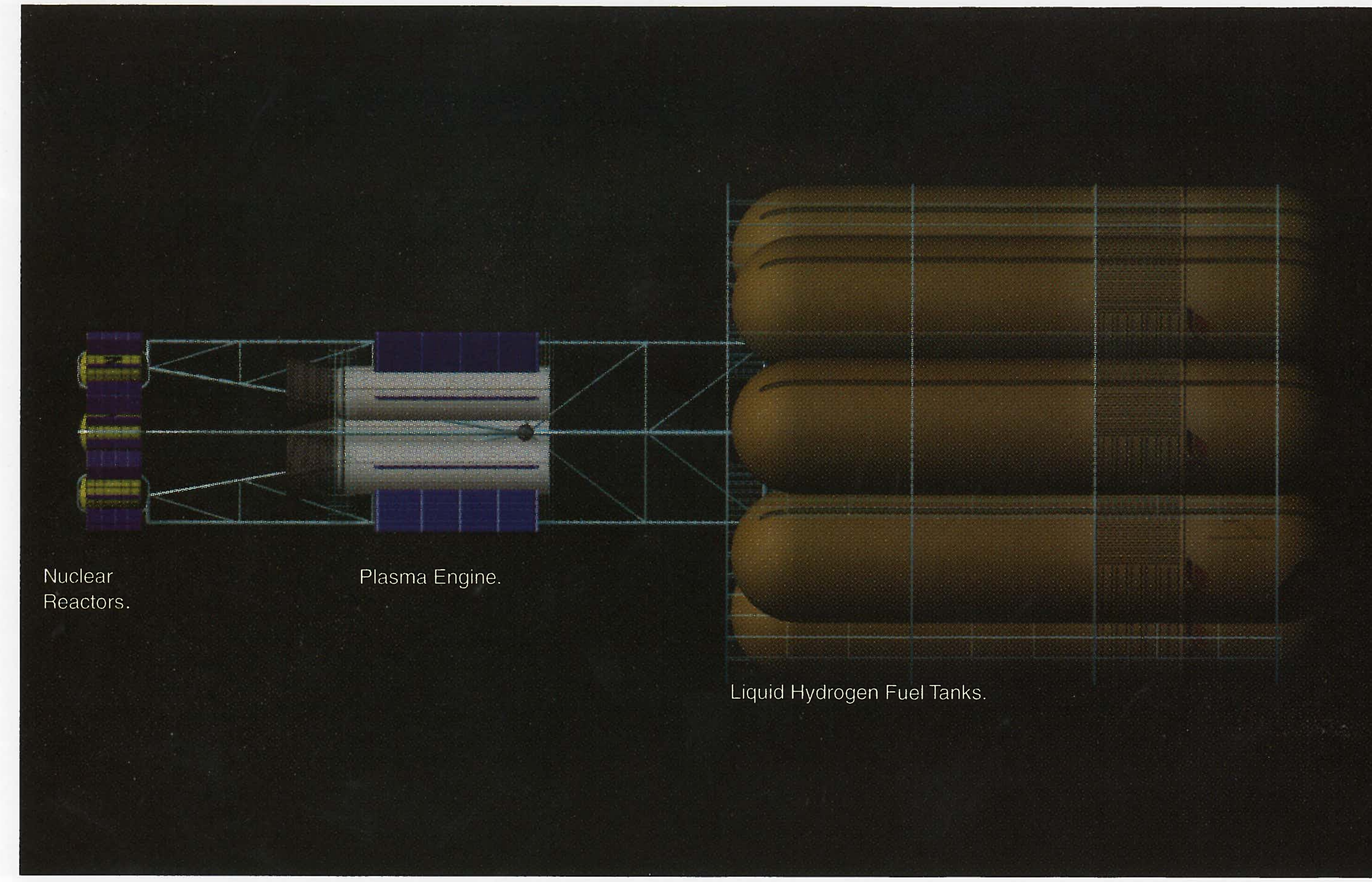
Nuclear energy would power the process.

VASIMR is a monopropellant engine that will most likely use liquid hydrogen as the fuel source. An estimated 12 mW of electricity will be required to power the plasma process in order to achieve a reasonable thrust level. A relatively small amount of this electricity (100s of kW) would be applied to provide power to the crew transfer habitats (*TransferHabs*) to support guidance, navigation, life support, attitude control, telemetry downlinks, active thermal control and command and data handling. Presently, nuclear energy offers the only know practical option that might be applied.

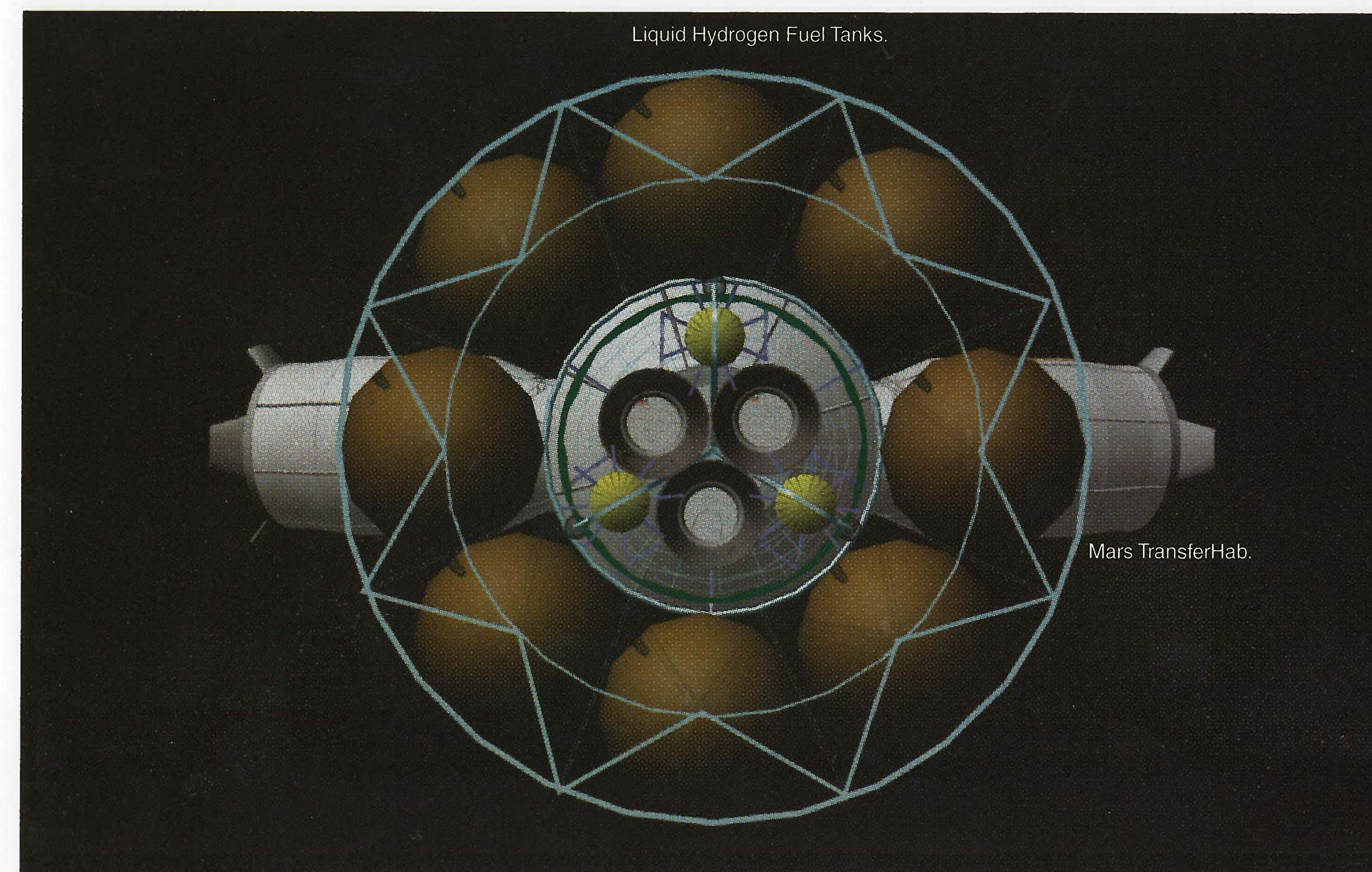
VASIMR MTV Showing Nuclear Reactors and Plasma Engine Deployed.



Side View.



End View Showing TransferHab Attached.



The Mars Transfer Habitat (TransferHab)

Transfer vehicle hydrogen fuel tanks offer space radiation shielding.

TransferHab will provide crew living and activity accommodations, life support systems and expendable supplies during periods of travel between Earth and Mars orbits. This 15 ft. diameter, 45 ft. long module will be positioned within the area surrounded by the VASMIR MTV's liqiud hydrogen fuel storage tanks to offer protective shielding from cosmic and solar radiation.

Facilities would accommodate crews of 8 people.

SICSA's baseline plan provides facilities and expendables for a crew of eight people over periods lasting up to approximately 500 days. Some of these individuals may remain in *parking orbits* in the vicinity of Mars while others engage in surface pursuits. Those who go to the surface will ascend to reenter the TransferHab for return to LEO at the conclusion of each mission.

Crew boarding intercept will occur in a high Earth orbit .

Crews will initially board the modules in a high Earth orbit beyond the radiation-intense Van Allen Belts, using special *Crew Transfer Vehicles (CTVs)* to access those intercept points.This will avoid the necessity of consuming large amounts of fuel to rapidly accelerate the VASIMR MTV through that dangerous area.

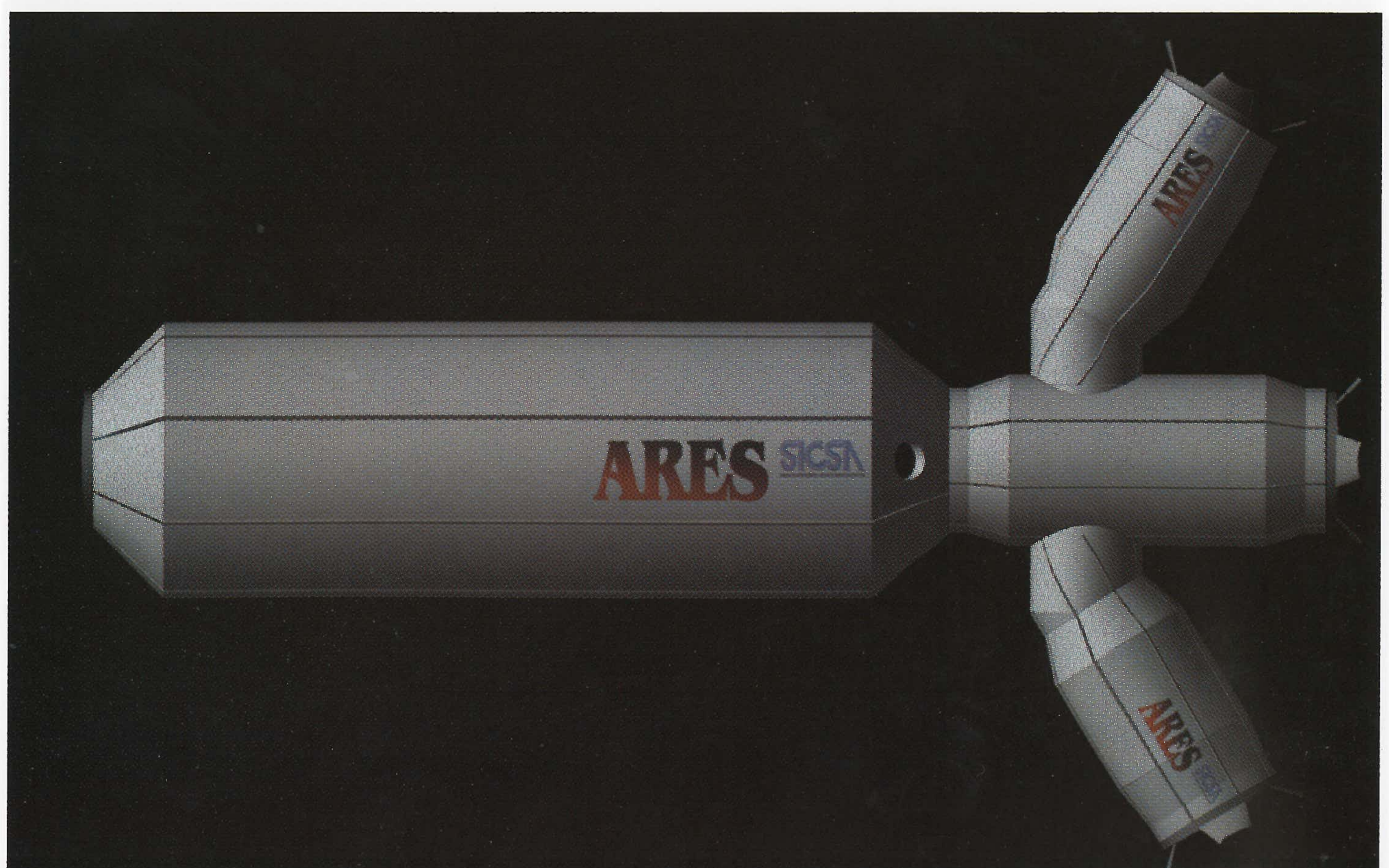
Most operations will be under very low-gravity conditions.

TransferHabs will operate under very low-gravity conditions. The module design applies a *banana split* internal configuration scheme, and is similar in many aspects to conventional modules which comprise the International Space Station (ISS). This standard arrangement provides a relatively efficient floor plan layout and long line of sight to minimize claustrophobic conditions.

The small 15 ft. diameter modules must support diverse functions.

The TransferHab design provides for diverse operational requirements and emergency contingencies. Places for personal privacy, recreation and exercise are essential to crew morale, health and performance. Facilities and equipment for scientific, medical and maintenance functions are also incorporated.

TransferHab with Docking Interfaces for Other Elements.



TransferHab Living Area.

TransferHab Living Area.

The Mars Surface Habitat (MarsHab)

The 45 ft. diameter, 200 metric ton module is designed to meet human operations, Earth launch and Mars landing requirements.

Relatively large 45 ft. diameter habitat modules are proposed to support eight-person crews for surface missions lasting as long as 500 days. These *MarsHabs* will incorporate means to accomplish soft landings, including: a support structure containing rocket engines and hydrogen-oxygen propellant tanks for propulsive descent braking; shock absorption units; and four sets of titanium solid wheel assemblies for module relocations on the surface. This landing apparatus, complete with propulsion elements, is referred to as the *Adaptable Truss Landing Structure (ATLaS)*.

Interior layout and equipment planning is similar to Earth facilities.

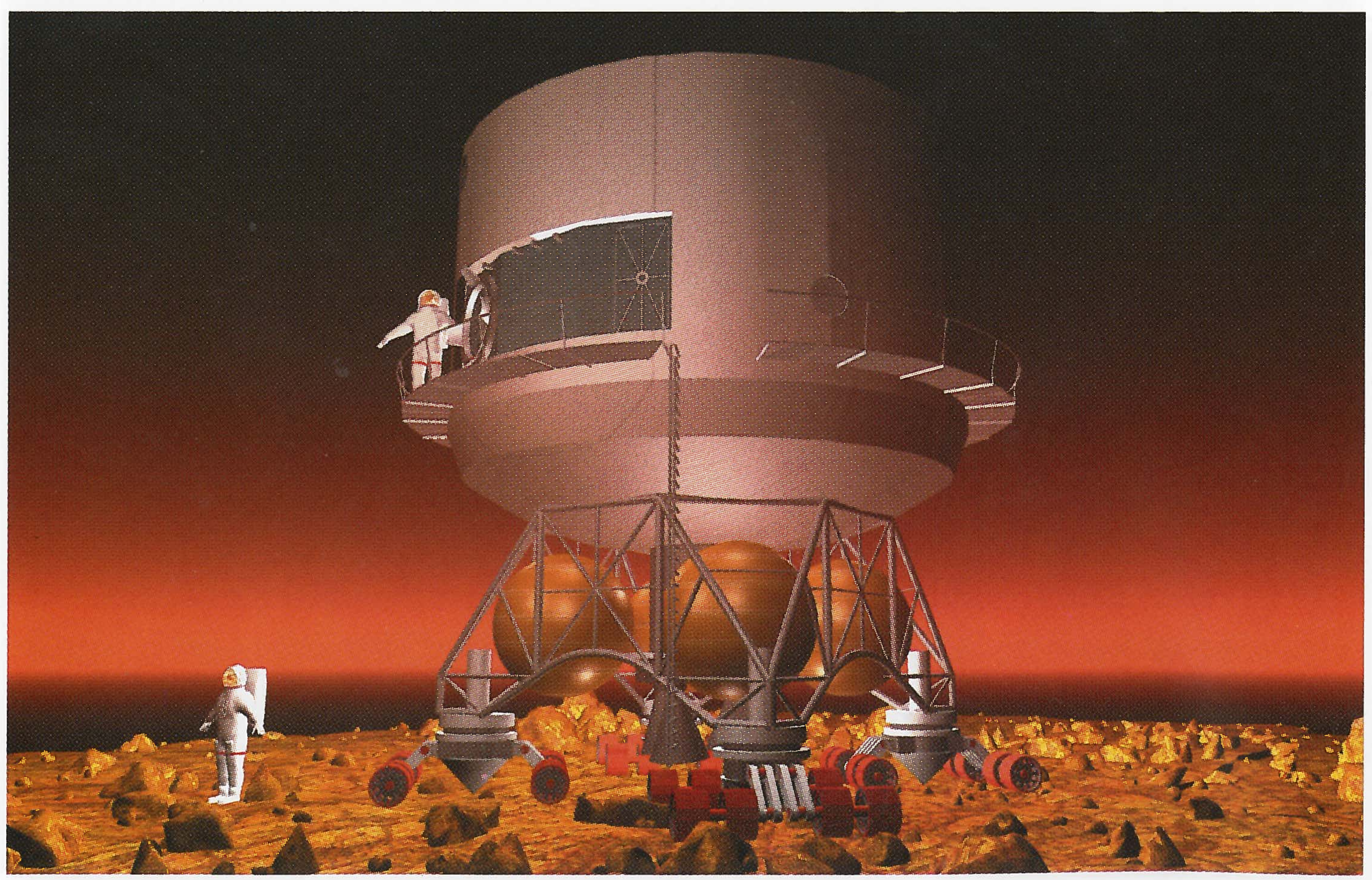
The total MarsHab mass, complete with ATLaS and propellant, is estimated to be approximately 200 metric tons. This size was established by analysis of crew living and activity support needs in combination with design considerations associated with Earth launch and Mars surface landing requirements.

Unlike TransferHab, which supports very low-gravity operations, MarsHab will function exclusively under Mars gravity conditions (0.38 Earth gravity). In this regard, the module interiors will be much more like those on Earth than layout schemes and equipment provided on weightless space stations. Sleeping units, for example, must be oriented horizontally, and toilets can operate with gravity flush.

Stored water provides radiation shielding for a solar storm shelter.

Like TransferHab, the MarsHab will incorporate a substantially closed life support system which incorporates means to reclaim, purify and reuse as much water as possible. Stored water will surround a radiation storm shelter which can provide emergency radiation shielding during periods of dangerous solar flares. Some oxygen for breathing and airlock replenishment will be obtained from CO_2 collected from the Mars atmosphere. Primary electrical power will be provided by small external mobile nuclear reactors which are supplemented by fuel cells and batteries for auxiliary needs and emergencies.

MarsHab with ATLaS Propulsive Landing and Mobility System.



MarsHab Sleeping Quarters.

MarsHab Galley and Wardroom.

Mars Surface Laboratories (MarsLabs)

Expandable modules offer means to launch and land larger facilities.

SICSA 's *First Mars Outpost* plan anticipates a need for laboratory facilities with largest practical internal volumes that exceed launch payload envelope constraints associated with MarsHab. Such facilities can be valuable to support hydroponic gardening to supplement less appetizing packaged food supplies brought from Earth, as well as possible aquaculture, animal breeding and other activities. Two different types of expandable module design approaches have been considered to provide these capabilities.

An inflatable approach can use the ATLaS landing system.

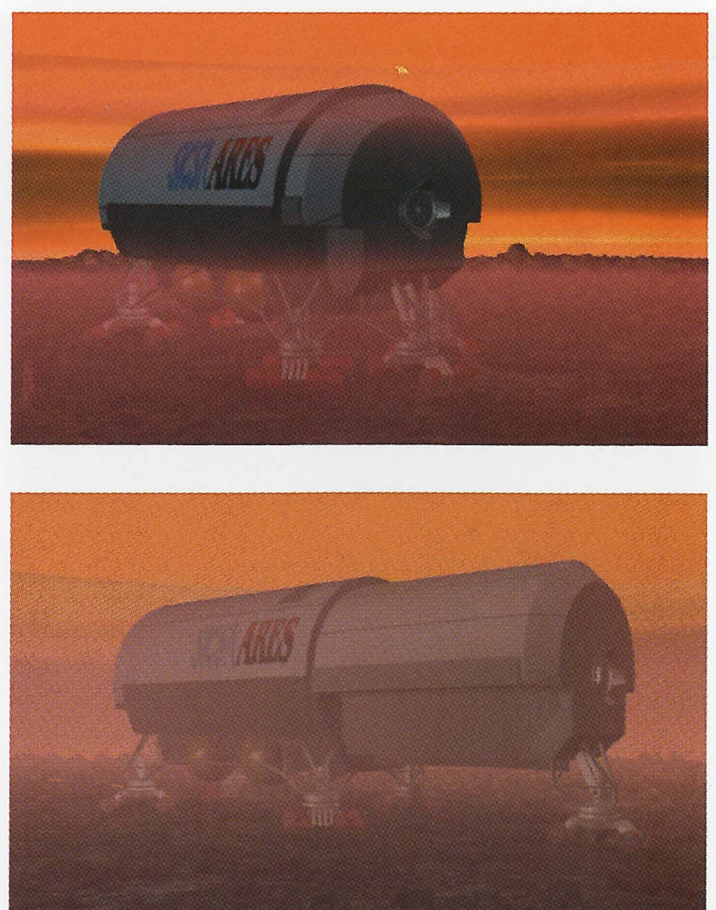
An inflatable laboratory module concept combines certain structural and equipment elements used for MarsHab with a pliable, pneumatically-deployed pressure vessel which is compactly packaged for Earth launch and descent to the Mars surface. Common structures and equipment include the ATLaS landing system and module berthing interfaces. Water is stored at the bottom level to lower the center of gravity to assist a stable landing. Following pressurization of the soft pressure vessel on the surface, crews, working under shirt sleeve conditions, attach internal floors and utility systems to tensioned cables which are pre-incorporated into the soft structural enclosure. Equipment systems and supplies can then be positioned and attached in appropriate locations.

Telescoping modules would land horizontally, and then extend in length.

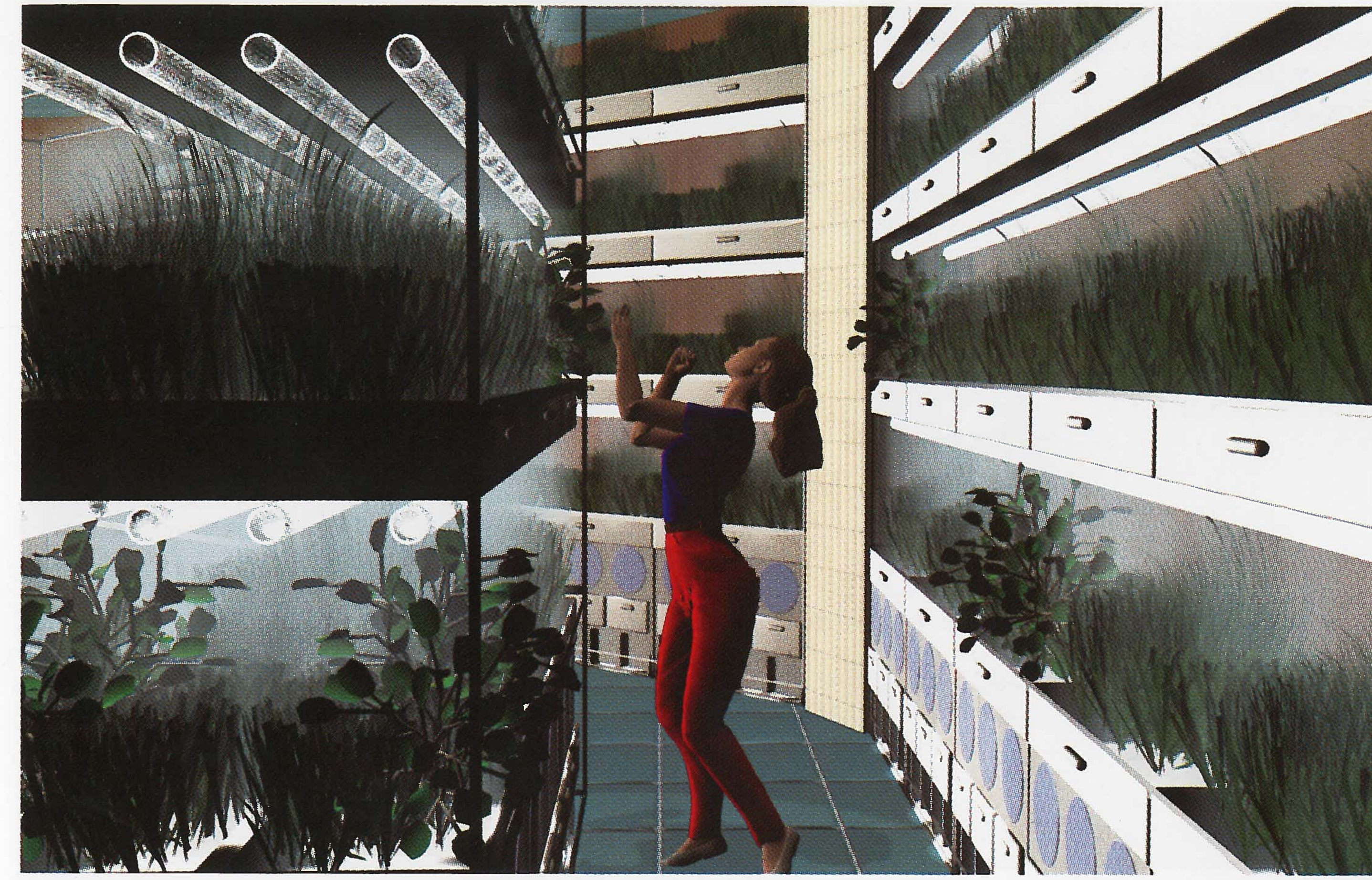
A telescopic laboratory module concept provides for a two-section pressure hull that enables one portion to be stowed within the other for efficient Earth launch and to facilitate surface landing. Following arrival and final positioning on Mars, the inserted section is pneumatically deployed like a piston to fully extend the module. Upon reaching the point of full extension, an internal perimeter pressure seal lockup system that incorporates interfaces for utilities is connected. When pressurized, crews, under shirt sleeve conditions, can relocate and install internal structures and equipment that have been stored in the telescoping section for transit and landing.

Inflatable MarsLab Deployed.

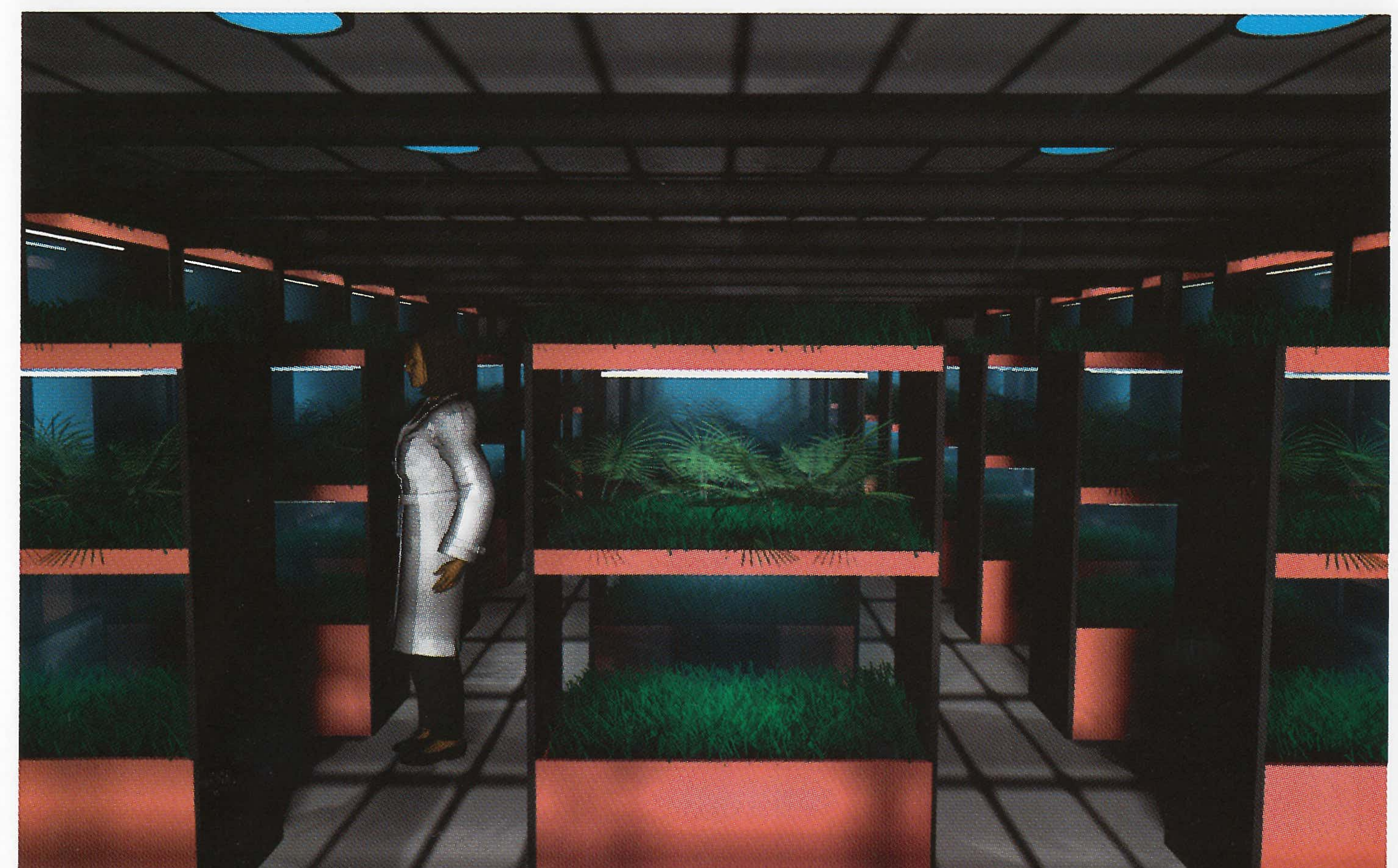
Telescoping MarsLab Undeployed and Deployed.



Inflatable MarsLab Interior.



Telescoping MarsLab Interior.



Crew Earth Launch, Mars Ascent and Earth Return Vehicles

Dependable lift-offs from Earth and Mars plus returns from LEO are primary requirements.

Human Mars surface mission planning must include safe and reliable means to launch crews from Earth and Mars surfaces and return them home from LEO. These objectives will require the development of special vehicles that can be based upon alternate technology concepts.

A proposed *Crew Transfer Vehicle (CTV)* would be used to launch the eight-person crews from Earth to a TransferHab intercept point beyond the Van Allen Belts. SICSA 's CTV concept is an enlarged version of a winged X-38 vehicle design that has been under development by Boeing. The CTV can also be used as a *Crew Return Vehicle (CRV)* to bring voyagers back to Earth from LEO at the conclusion of their missions. This approach offers the advantage of conventional aircraft-type landings at desired airport locations.

Crew Earth returns can utilize parachuted capsules or winged gliders.

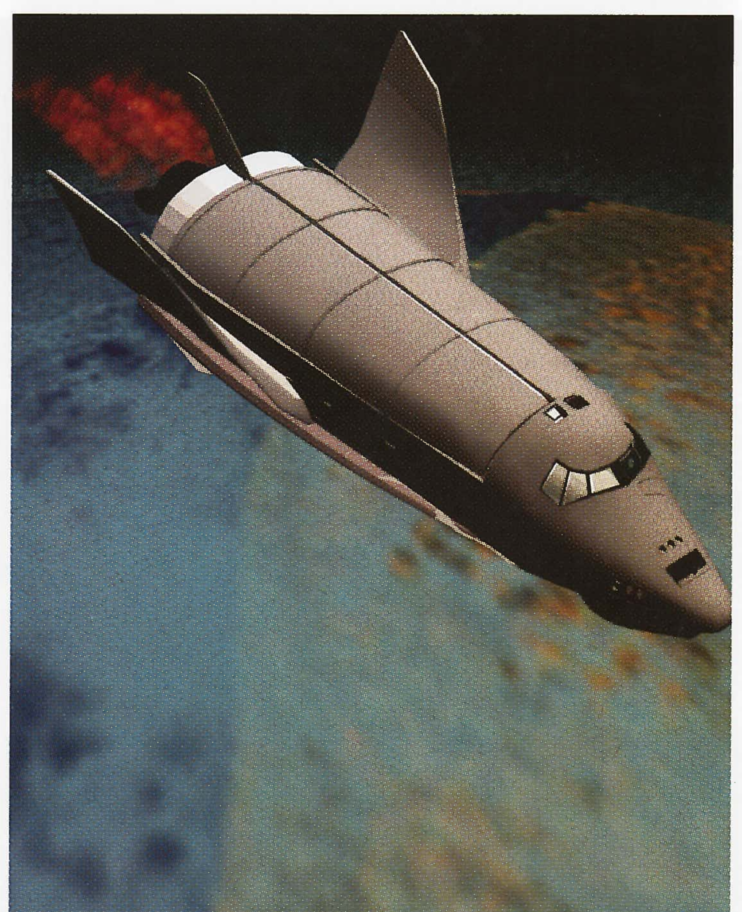
Another CRV approach would use a landing capsule similar to those developed for NASA's Mercury, Gemini and Apollo Programs. This concept does not provide the same level of operational convenience afforded by the winged vehicle, but its greater simplicity and lighter weight would reduce development and mass transfer costs. SICSA has explored an option that utilizes the crew pod of a *Mars Ascent Vehicle (MAV)* for dual use as a CRV capsule. The MAV design would lift a crew and samples off the surface, then intercept a TransferHab parked in Mars orbit for return to LEO.

Oxygen from the Mars atmosphere can offer a MAV propellant supplement.

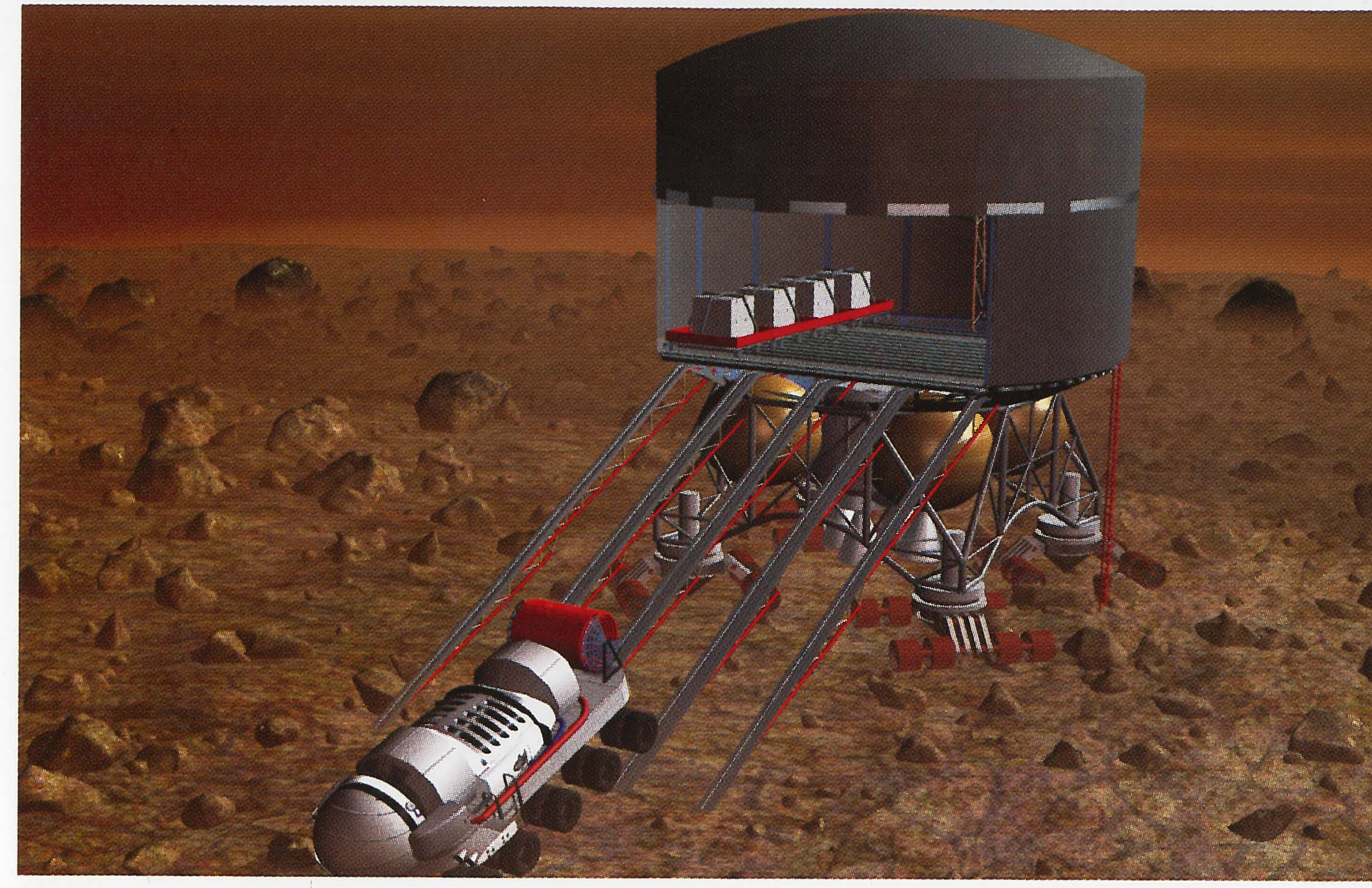
Practical efficiencies may call for reducing MAV launch fuel that must be brought from Earth by obtaining oxygen for liquid oxygen/liquid hydrogen (LOX/LH_2) thrusters from carbon dioxide in the Mars atmosphere. Accordingly, the MAVs would be dispatched to the Mars surface before crews are sent in order to allow adequate processing resupply time. The same rockets and type of fuel would be used for Mars surface landing and lift-off.

A MAV Crew Pod Might be Used as CRV.

X-38 Type CTV/CRV Concept.



Logistic Module Unloading a MNU and Cargo.



Logistics and Support Elements

A settlement on Mars will require periodic deliveries of supplies and equipment from Earth.

Mars surface programs will require means to transport and land a variety of consumable supplies and equipment items that will be periodically needed over time. Examples of these items can include water and chemical nutrients for MarsLab hydroponic gardening, hydrogen for MAV propellant, construction and repair equipment, surface excavation and material processing equipment, atmosphere collection and containment systems, manned and telerobotic surface transport vehicles, and electrical power generators.

LMs are designed to support construction/ assembly activities as well as to carry cargo.

SICSA's proposed *Logistic Module (LM)* uses the same ATLaS landing system that is incorporated into the MarsHab and the inflatable version of MarsLab. This common design approach will reduce engineering development and fabrication costs, and will support early as well as evolutionary stages of surface operations and settlement expansion. The LM can accommodate different cargo carrier options as required for specific needs. Included are a temperature-controlled and potentially pressurized container for volatiles, and an open structure option that provides pallets and attachment fixtures for other supplies and equipment. The LM can also be outfitted with cranes for off-loading cargo and supporting surface construction. Deployable ramps will enable wheeled vehicles to roll to the surface.

Small mobile nuclear power generators will produce electricity for positioning facilities on site and for operational needs.

Electrical power generation for surface operations and facilities will be provided by small *Mobile Nuclear Units (MNUs)* that offer two important support functions. First, they are automatically dispatched to rendezvous with MarsHabs, MarsLabs and LMs after they land, establish electrical interfaces with their ATLaS drive systems, and provide power to move these elements to desired site destinations. Then, after those facilities are appropriately positioned in place, the MNUs will provide electricity to the habitat and laboratory modules as their primary source of operational energy through long power lines that enable remote placement away from habitats for radiation protection.

Surface Development and Operations

Mars outpost development is planned to support evolutionary stages.

Planning and design of surface elements and systems responds to a number and variety of site development priorities associated with crew safety, configuration flexibility and operational optimization. These considerations have taken future evolutionary possibilities as well as initial outpost requirements into account. This is essential to ensure that each development stage provides a useful facility infrastructure and expanded human and material resource base to support others that will follow.

Element standardization and redundancy offers flexibility and safety.

Important safety provisions demand contingency options for potential life-critical facility and equipment failures, fires, operational accidents and other emergencies. One way this is accomplished is by providing redundant habitable elements and components. For example, a MarsLab can serve as a safe haven with autonomous life support systems and separate consumable supplies in the event that a connecting MarsHab becomes dysfunctional. All modules also provide at least one back-up system for each vital component. Landing and launch areas are planned to be located at a safe distance from these facilities to avoid hazards resulting from flight operations.

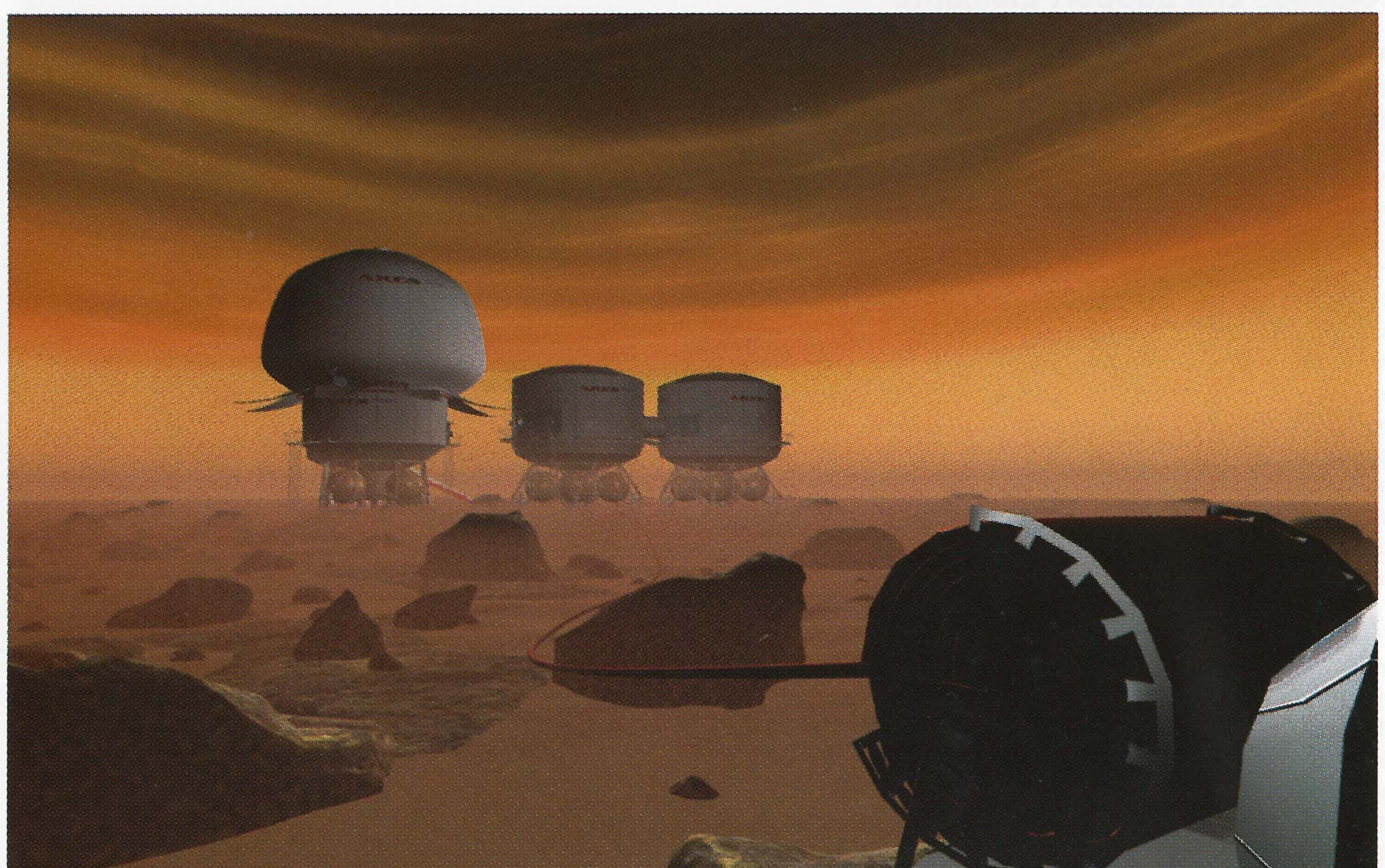
A variety of layout schemes and growth strategies are possible.

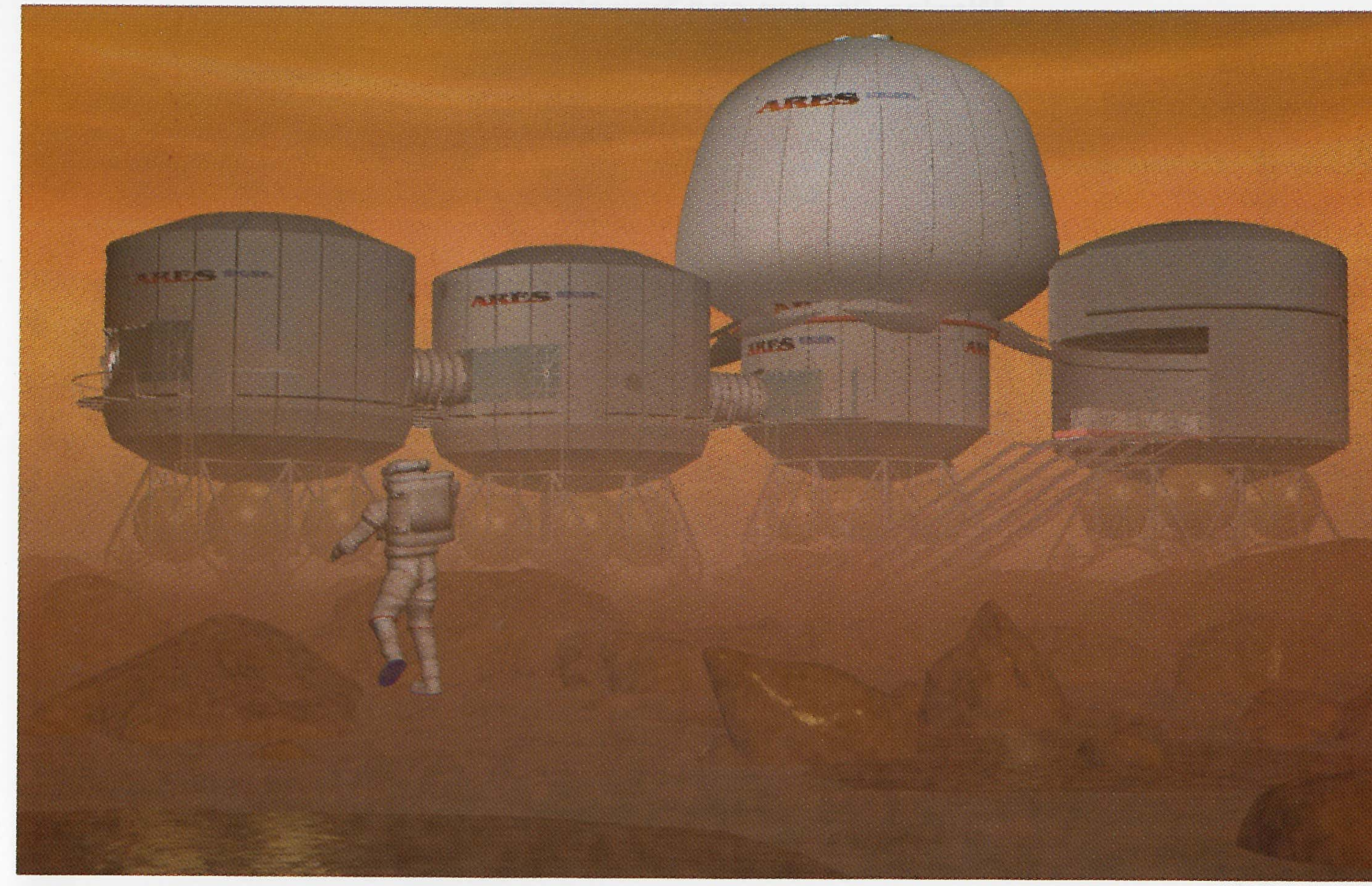
Multiple MarsHab and MarsLab berthing ports offer optional connecting points to enable alternate interfaces and site layouts. Additional modules can be installed as required over time. This is necessary to provide versatile adaptation of the modular element configuration to special site terrain conditions and evolutionary mission requirements.

Human operations are facilitated by rovers and telerobotic systems.

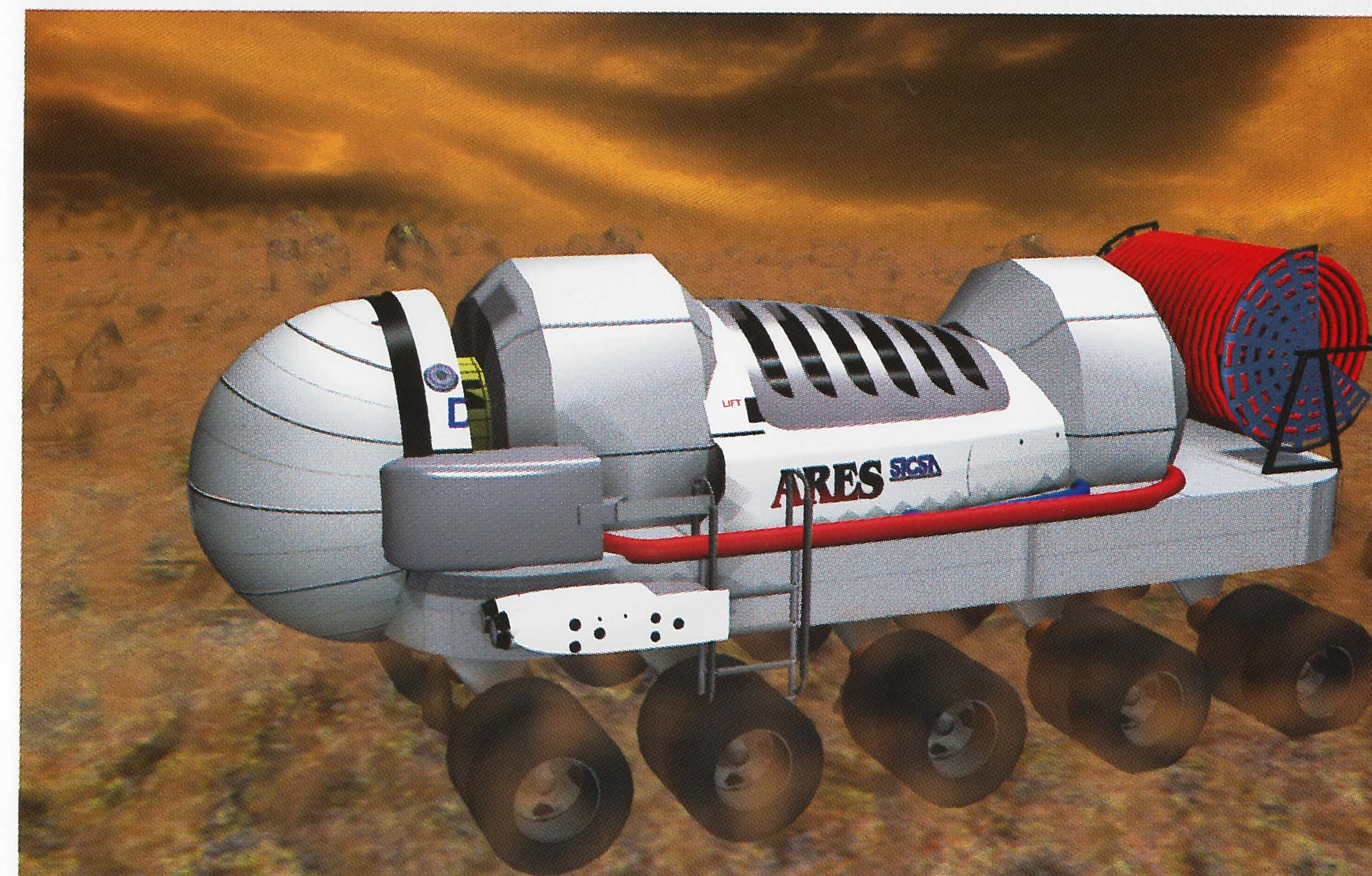
Large airlocks with ample volumes for EVA suits and equipment storage are incorporated into MarsHabs, along with a powered system to lift EVA crews and soil samples to the interior access level.The lift system will also facilitate placement of connecting elements between modules during assembly procedures. Manned rovers and telerobotic systems will be provided as required to facilitate surface operations.

MarsHabs Attached to an Inflatable MarsLab.





Mobile Nuclear Power Unit (MNPU).



Mission Phases and Trajectories

Voyages to Mars and back will involve several different mission phases.

Mars settlement development will require several mission architecture phases. The first entails launches of equipment, supplies and crews from the Earth's surface to Earth orbits. This is challenging because the launch vehicles, laden with massive payloads, must forcibly overcome Earth's gravity and atmospheric drag. The second stage involves transfers out of an Earth orbit into a Sun-centered orbit. This spacecraft must still fight against the pull of Earth's gravity, but atmospheric friction ceases to be a factor. Instead, radiation becomes an issue, and will remain a problem until returning to Earth. The mission then moves into the longest phase, the transfer orbit stage, as the vehicle travels towards Mars.

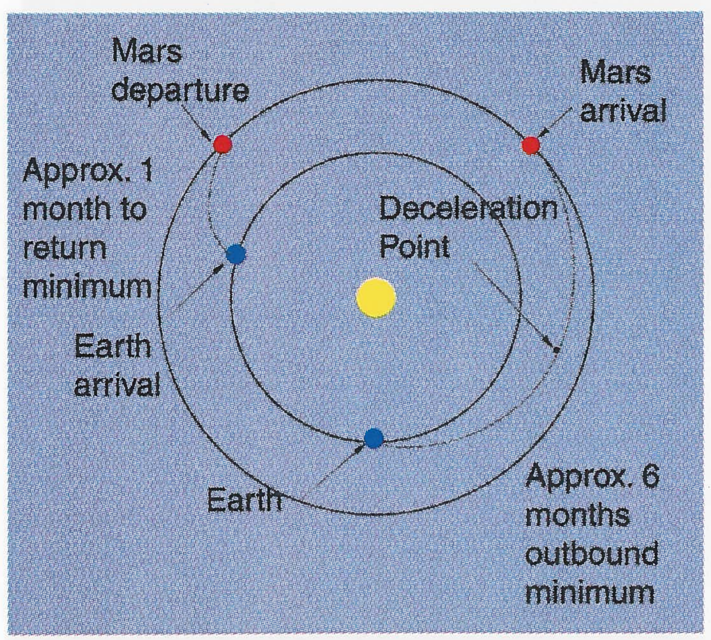
Using the VASIMR MTV, two trajectory options can be applied.

Applying the VASIMR MTV approach, the transfer orbit stage can apply two alternate trajectory options: a *Conventional Constant Acceleration Trajectory (CCAT)*; or a *Hyperbolic Blow-By Mars Orbit Rendezvous (HBBMOR)*. The CCAT option provides that the MTV begins to slow down at the halfway point between Earth and Mars so that the entire vehicle complex enters the planet's orbit. The HBBMOR option has the MTV accelerate until approaching Mars before it slows down, deploying only surface elements into the planet's orbit and atmosphere, and then proceeding to a large parking orbit where it will remain until it is time to return back to Earth. In both scenarios, the MTV Earth return legs occur in the reverse order.

Aerobreaking will slow elements upon entering the Mars atmosphere for landing.

Transfers from Sun-centered orbits to Mars orbit and then to the surface present special difficulties. Elements that enter the Mars atmosphere will be subjected to high frictional heat loads and will expose crews and cargo to rapid deceleration forces. The blunt ballistic shapes of these elements will facilitate this aerobraking effect prior to descent, using propulsive rockets to accomplish soft landings. Following surface operations, the crew will use an Ascent Vehicle to intercept with a MTV TransferHab in Mars orbit for their return trip to LEO, and finally, back to Earth.

Conventional Constant Acceleration Trajectory.

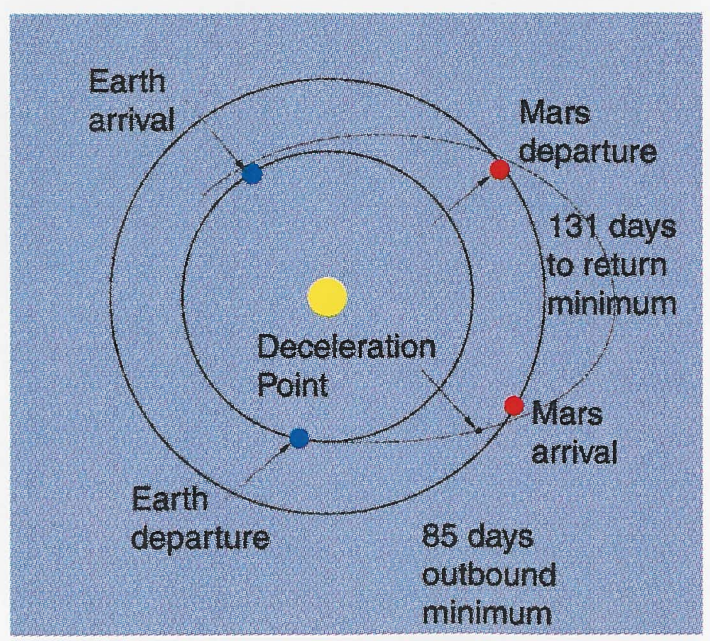


Using a low-thrust engine,the MTV continues to accelerate until it reaches the halfway point between Earth and Mars.

It then turns around to thrust in the opposite direction in order to slow down enough to directly enter into Mars Middle Orbit (MMO).

There are no planetary alignment restrictions, and shortest voyages to MMO and back to LEO will require about 6 months, and 1 month, respectively.

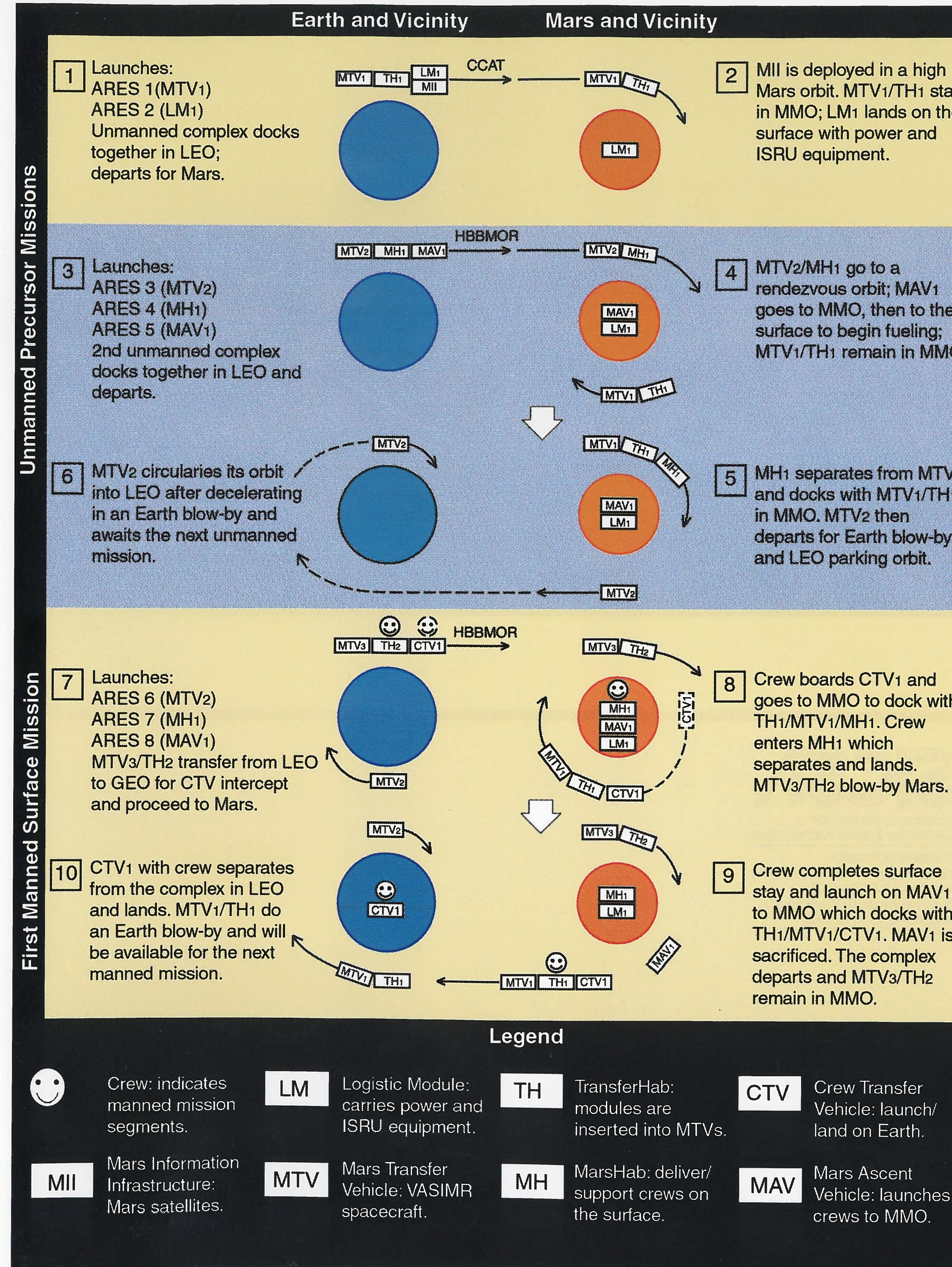
Hyprobolic Blow-By Mars Orbit Rendezvous.



The fastest trajectory (approx. 85 days) utilizes a low-thrust engine for constant acceleration until the MTV approaches the vicinity of the planet.

The crew then transfers to a MarsHab which separates from the MTV, is captured by the Mars atmosphere, slows down,and lands on the surface.

The MTV then reverses direction to decelerate,allowing Mars to catch up with it in about 135 days.



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