MICROWAVE LAUNCHES OF SMALL PAYLOADS

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This brief article describes a concept to demonstrate low-cost access to space. It uses a ground-based microwave transmitter and small satellites integrated with the launch vehicle. It would also use advanced beamed power techniques, including one developed under SSI sponsorship by Professor Yuri Raizer and Leik Myrabo. An integral APO GEE kick motor is that last vestige of traditional chemical rocket technology.

As Myrabo implies, the limited energy density of chemical fuels and the need to carry both the capital-intensive engine and tankage places a strict lower limit on cost-per-pound-to-orbit delivered chemical rocket. Even the best chemical rocket will, at some level of Earth-to-orbit traffic, become uneconomical compared to beamed power launchers or Earth-to-orbit mass-drivers or light gas guns.

To make the transition to a cheaper launch technology, two things are necessary. The first is a technically mature launch technology that is one with well-understood economics and well-understood and low technical risk. The second is a large enough demand for launch services to make the investment in the new technology profitable.

SSI's members know that the ultimate prizes for the breakout into space are the vast quantities of energy and materials available there argues here for the market.

Microwave Propulsion

The use of microwave and millimeter wave beamed energy for propulsion of vehicles in the atmosphere and in space has been under study for at least 35 years. Right now the payload of chemical-fueled rockets is a minute percentage of the total weight of the rocket at lift-off. This means it costs more than $3,000 per pound to lift the payload into low-Earth orbit. The HPM-boost alternative would leave the heavy and expensive components on the ground (or in space), not in the vehicle. Reducing the weight of the spacecraft to the absolute minimum will also lower the overall cost of putting it into orbit, because ultimately, mass is the real enemy. More efficient launch propulsion means less propellant, minimal tankage penalty and lighter engines.

Airbreathing HPM Pulsejets

For maximum performance in acceleration, future engines designed for transatmospheric aerospacecraft are likely to encompass both airbreathing and rocket elements, and transition through various propulsion modes as a function of flight mach number and altitude. The principal advantage of airbreathing engines is that the propulsive fluid is provided by the surrounding environment, so thrust is developed by means of momentum exchange

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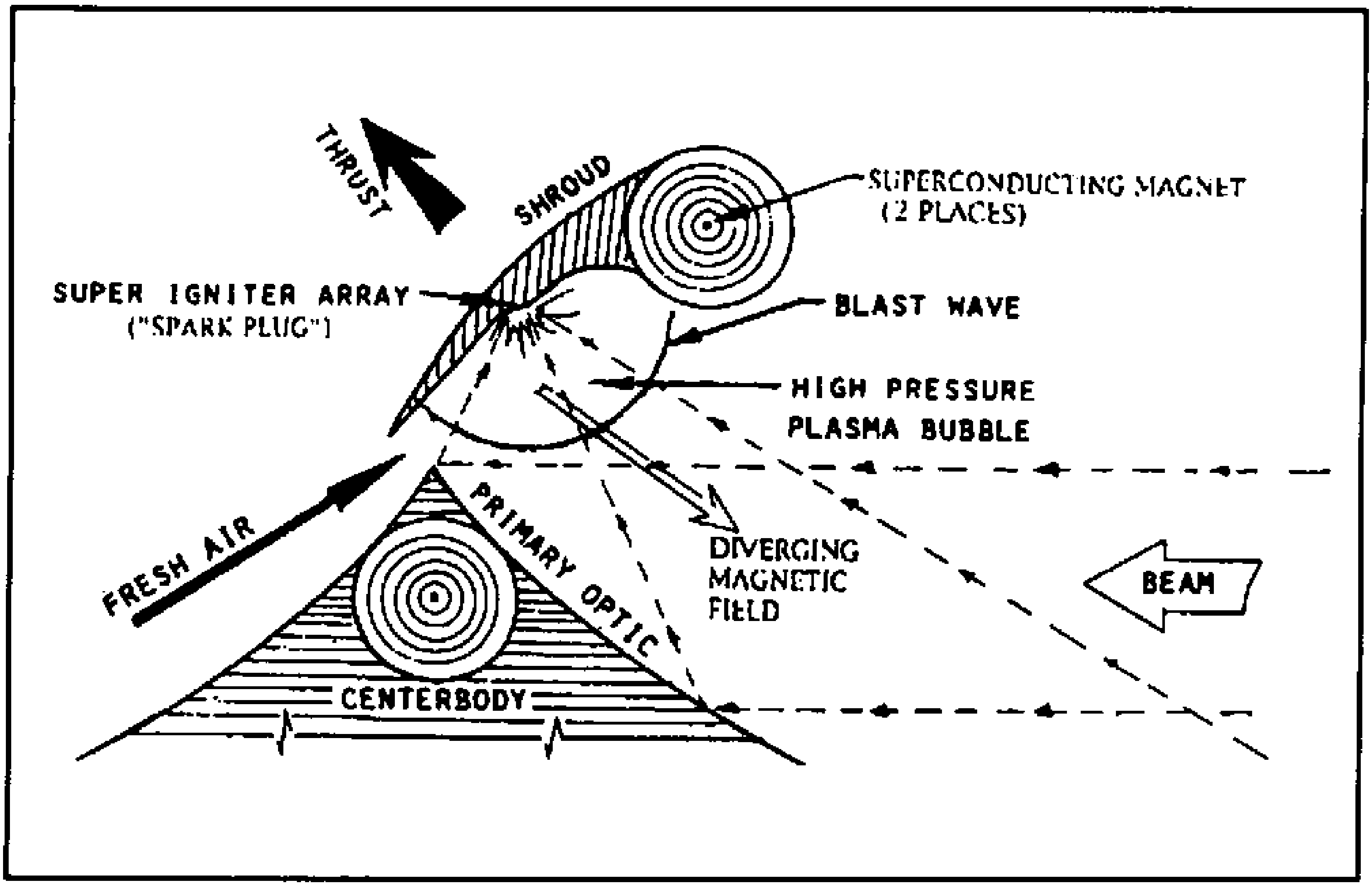

Figure 1. Focal Geometry of HPM Pulsejet Engine (Showing location of Super-Igniter Array).

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with the atmosphere. In contrast, rocket engines require that all the propellant be carried aboard the vehicle.

The airbreathers we are most familiar with are the gas turbine power plants that propel jet fighters and transport aircraft. The basic turbojet, perhaps the simplest turbomachine, operates on the Brayton thermodynamic cycle and requires an inlet diffuser, compressor, combustor, turbine and nozzle to generate thrust. Beyond Mach 2 (i.e., twice the speed of sound), the heavy mechanical compressor becomes a useless steel anchor because the compression function is now provided by the supersonic air ramming into the inlet.

In sharp contrast with such turbomachines, the basic ramjet configuration can be likened to a flying "stovepipe," open at both ends, with a variable geometry air inlet and rear exhaust nozzle; in the center of this engine, combustion of the fuel takes place at subsonic (engine air) velocities. Ramjet engines and their supersonic-combustion counterparts (i.e., scramjets) have a great liability in that they cannot develop thrust at subsonic flight speeds. All need some kind of boost engine to get them started; e.g., rockets or turbomachines which can add significant weight and complexity to the flight platform.

However, there is one variety of "flying stove-pipe" engine which can produce significant thrust levels from a standing start—the pulsejet engine. Unlike the Brayton cycle engines, which are classified as "constant pressure" machines because at any engine station the pressures are constant with time (at a fixed throttle setting), the pressures anywhere within pulsejet engines fluctuate with time at a constant rhythm.

Chemical-fueled pulsejet engines have been built to operate in both combustion and detonation modes, although we are most familiar with the former. The first practical application of airbreathing pulsejet engines appeared with the German V-1 "Buzz Bomb" developed during World War II to rain terror over London, England.

A recent resurgence of interest in Pulsed Detonation Engines (PDE) indicates airbreathing pulsejet research is alive and well (Ref. 1). Some experts believe that PDEs are the short path to ultra-high performance supersonic and hypersonic acceleration engines of the future.

The role of the high-power microwave beam in a pulsejet engine is as an external ignition/detonation energy source. The propulsive microwave beam is transmitted to a receiving antenna on the spacecraft, where it is focused directly into the HPM pulsejet engine (Fig. 1). The thrust surface is equipped with a "super-igniter array," which consists of a large number of wires imbedded vertically into the surface. These wires act as dipoles and are tuned to the HPM wavelength. The igniter array brings about electrical air breakdown by acting as a spark plug in the airbreathing propulsion system.

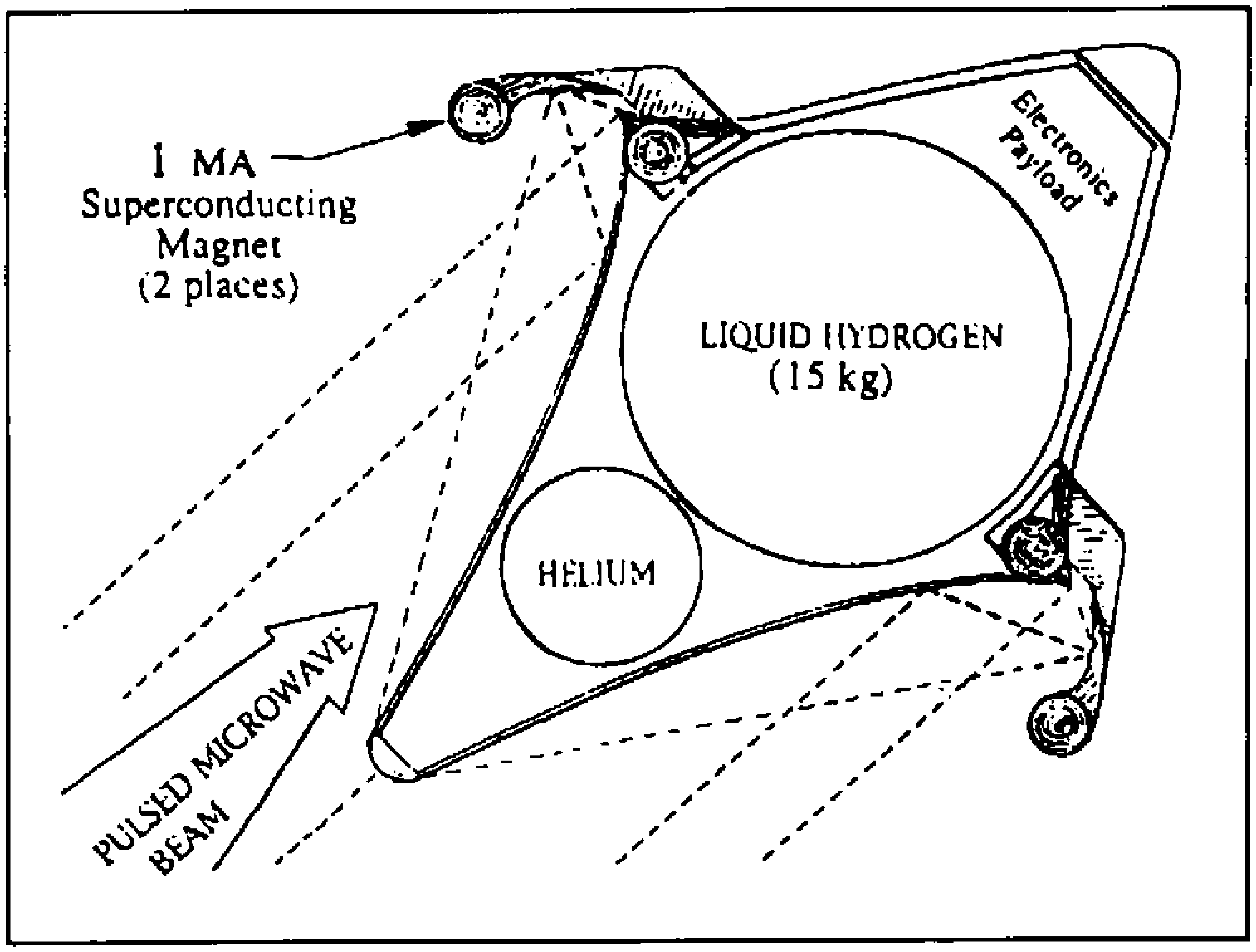

Figure 2. Ultralight microwave-boosted microsatellite (lift-off mass-30 Kg).

Vehicle Description

In this design, the engine is integrated with the receptive optics and spacecraft airframe—including propellant tank, pressurization and delivery system, as well as electronics, communications and control systems. Designs for a small "Lightcraft Technology Demonstrator" have been developed in connection with a recent government-sponsored advanced propulsion program based on lasers (Ref. 2). A similar "ultralight" microspacecraft can be developed for use with a lower power ground-based microwave boosting station (see Fig. 2). Liquid hydrogen would be used for the microwave-heated rocket propellant.

The HPM-boosted spacecraft can be kept light by fabricating a pressurized tensile structure to serve as a "backbone" to the craft. The most advanced high-temperature carbon composites would be used. A sandwich structure with a thermal insulating core material might be used to inhibit frost or ice formation on the optical receiving antenna. The innermost layer of tank could be a thin aluminum skin as a vapor barrier. A protective coating of silicon carbine must be applied to the exterior optical surface as protection from the oxidizing high temperature engine exhaust.

Launch Scenarios

Launch of this ultralight, 15 Kg. spacecraft involves several steps:

- An initial velocity is given by a compressed air cannon using a sabot which quickly separates from the vehicle.
- At one second into the launch, the pulsejet engine is engaged and the vehicle climbs at a fixed angle. With the airbreating engine, only a small amount of liquid propellant is consumed as coolant for the reflector and hot sections of the engine. The vehicle accelerates toward Mach 5. With higher speeds and lower air pressure (due to increased altitude), the amount of thrust will decline. At 30 Km altitude the airbreathing pulsejet engine is shut off.
- The vehicle coasts upward through the region of the Paschen minimum pressure. At the desired altitude the craft pitches over into its final horizontal position, and begins to receive microwave power from a low-altitude relay satellite (see Fig. 4). The rocket begins again to increase speed to that needed for a circular orbit.

An alternate launch scenario in Fig. 5 portrays a direct boost to low-Earth orbit velocity without invoking an expensive space-based asset (i.e., the microwave relay satellite). This concept requires only the addition of a small "chemical kick" rocket to circularize the microspacecraft's orbit once the perigee is reached (see Fig. 6).

Further improvements in transatmospheric acceleration performance might be enabled by an "Air Spike" device (described in the Sept/Oct 1992 issue of *SSI Update*) to greatly reduce aerodynamic drag on the spacecraft forebody.

HPM Boost Facility

The ground-based boost facility for HPM transmission is seen as a phased array of independently phased elements which produces a converging and concentrated beam (see Fig. 7) upon the spacecraft. A recent collaborative technical paper (Ref. 3) with J. Benford (Ref. 4) examined this innovative launch system, and identified a beam power requirement of 30 MW to boost a 30 Kg spacecraft needing 15 Kg of liquid hydrogen.

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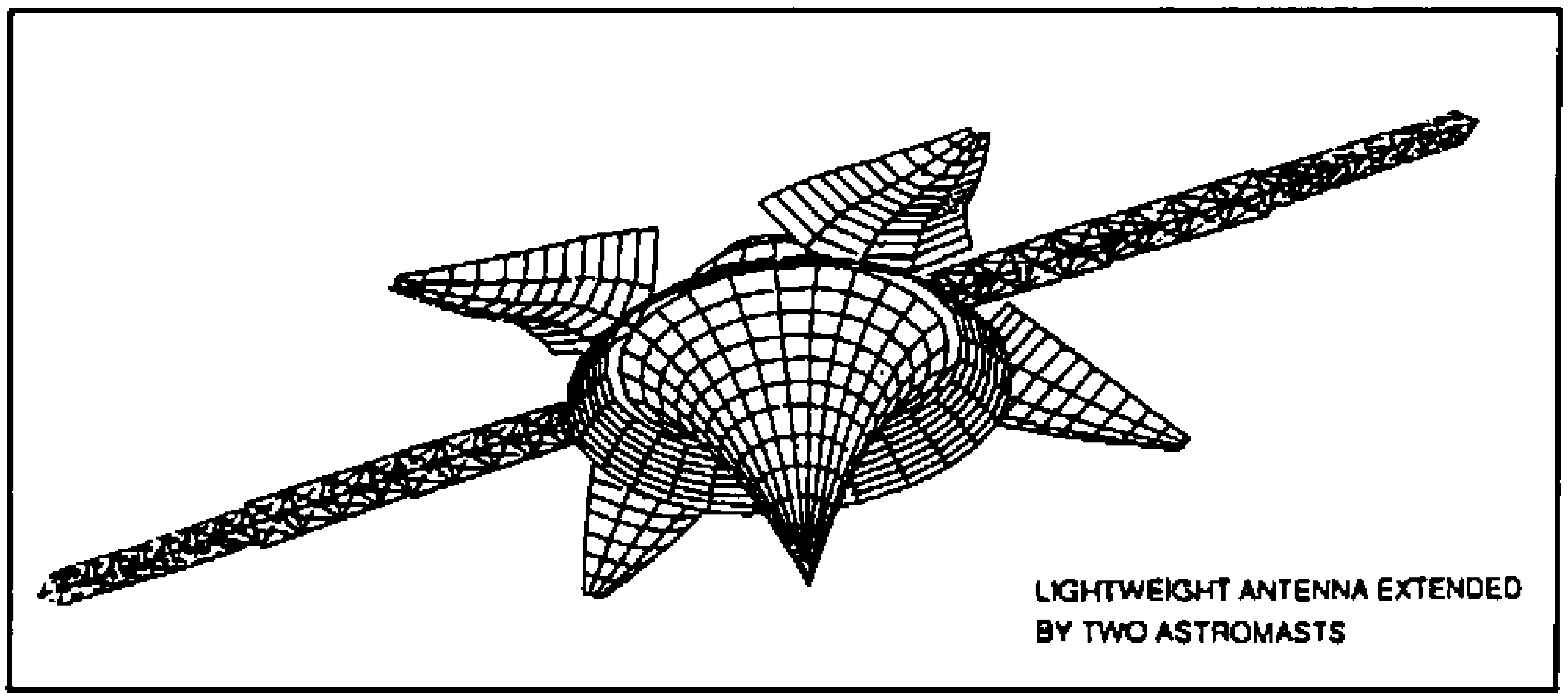

Figure 3. Solar cell panels and RF antenna deployed (during satellite mode).

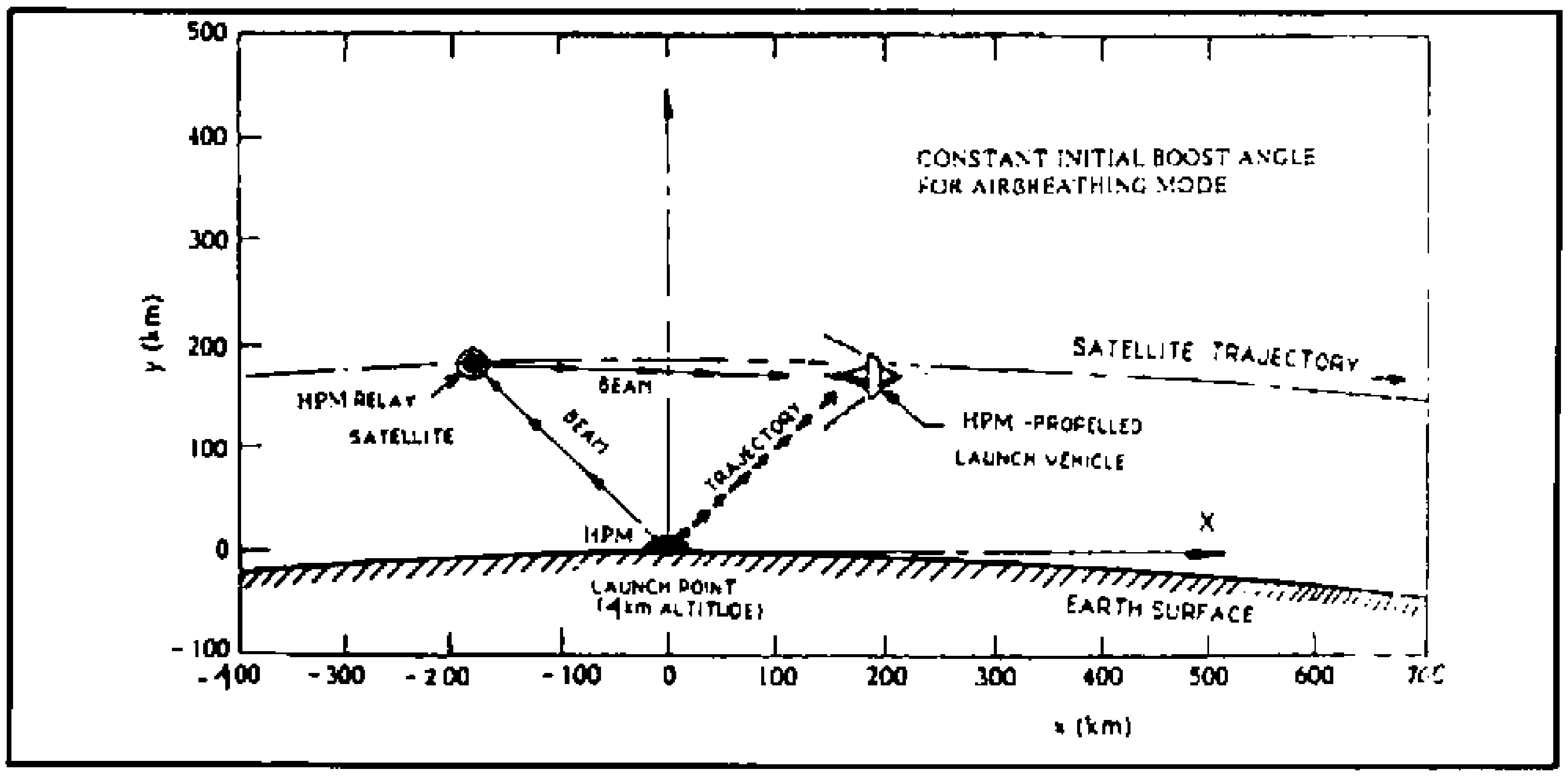

Figure 4. HPM launch with relay satellite.

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A transmitter aperture of 550 m and frequency of 220 GHz (an ideal atmospheric window) are necessary to focus power onto a 1 m diameter spacecraft receiver at a maximum range of 500 to 800 km—where orbital velocity is finally attained. A fixed array of slotted waveguide radiators might be preferred over a series of individual dishes for the transmitter. Gyrotrons appear to be the most promising millimeter wave sources, for which the present state of the art is 10 KW per device. In the near future, this average power level is expected to grow to 100 KW. Hence, 300 to 3000 sources are required to meet the 30 MW average beam power.

Applications

The next major revolution in communications may be within our reach: liberation from control of communication channels by large telephone companies or governments. Individual ownership of communication satellites—for business or pleasure—could cost no more than $21,000!

This revolution may come through the ability to launch 35-pound microsatellites (slightly heavier than the 31 lb. Explorer I launched into orbit by the U.S. on Jan. 31, 1958), with the aid of a 30 megawatt ground-based microwave launch facility developed with private resources. The difference between 1958 and today is that these specialized microsatellites are designed to carry 7 pounds of ultra-sophisticated modern microelectronics linked to a one-meter diameter telescope that can simultaneously act as a narrow band optical transceiver (see Fig. 2).

The satellite itself could cost just $15,000, and the microwave launch fee only $6000 more—for a total investment roughly equal to a new automobile or top-end microcomputer today. Custom features could be ordered to augment the basic package of a 75-watt solar panel, 20-watt-hr. rechargeable battery, communications/guidance electronics, magneto-optical data storage, attitude control/ pointing system and 1 m optic (see Fig. 3), customized—for extra cost, of course.

Next, imagine the many applications of microsats: accurate physical information about the Earth's environment, high-resolution images of specific locations, direct access to the space environment; information available now only to national governments, the military and large corporations. This revolution would also allow the exchange of information around the world without the filter of bureaucratic censorship. With virtual reality headsets, microsats would allow the freedom of space travel from the comfort and safety of home.

Microsatellites—linked to individual owners or groups of owners by small transmitters and their satellite dishes—will allow smaller users to bypass the expensive and closely-held corporate and government-owned information systems now in place. The potential is for thousands of privately owned satellites, which would increase the flow of information by reducing the cost and other restrictions on its transmittal.

Realistic microsat applications include interactive use of a one meter diameter space telescope; optical communications with ultra-high data rate transfer; Earth resources satellite capable of visible, infrared, ultraviolet and radar sensor wavelength observation; cellular phone communication and relay stations; space-based virtual reality; wandering asteroid/ planetoid threat detection and monitoring; explorationg for extraterrestrial resourses; launch detection, tracking and re-entry warning system; global positioning satellite (GPS) system; high resolution (to 8 cm in the ultraviolet) mapping; suborbital "space environment" testing of satellite equipment; and much more.

Cost

It is reasonable to assume that a mass-produced 15 Kg vehicle can be manufactured for a cost of about $1,000/Kg (the price of most high tech hardware today). Although the current cost of building a 30 MW microwave launch facility is estimated by Benford to approach $1000 million (largely dominated by the gyrotron and pulsed electric power supplies), economies of scale in mass production should ultimately enable HPM transmitter costs of $5 to $10 per watt. At this level, the concept is certain to capture the imagination of venture capitalists who would be willing to invest $150 million (roughly the price of a single Boeing 747 jumbo jet) in the project. If recovered over 10 years, based on an average of 16 launches a day (one every 90 min.), launch charges would be $3000 to $6000 for each microspacecraft.

The final launch costs for the satellite owner would be only 4% of the cost of using traditional chemical rockets.

Future Research

Future research on this low-cost alternative launch project will include analytic and experimental investigations of the propulsion dynamics of HPM detonations in a high magnetic field, at various air pressures. Airbreathing pulsejet experiments with HPM sources presently available at NRL, Physics International, Varian and elsewhere, would be required. Comparison of performance results for both laser and millimeter sources would also be beneficial to develop accurate wavelength scaling relations.

References

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2. L.N. Myrabo, et.al., "Transatmospheric Laser Propulsion," Final Technical

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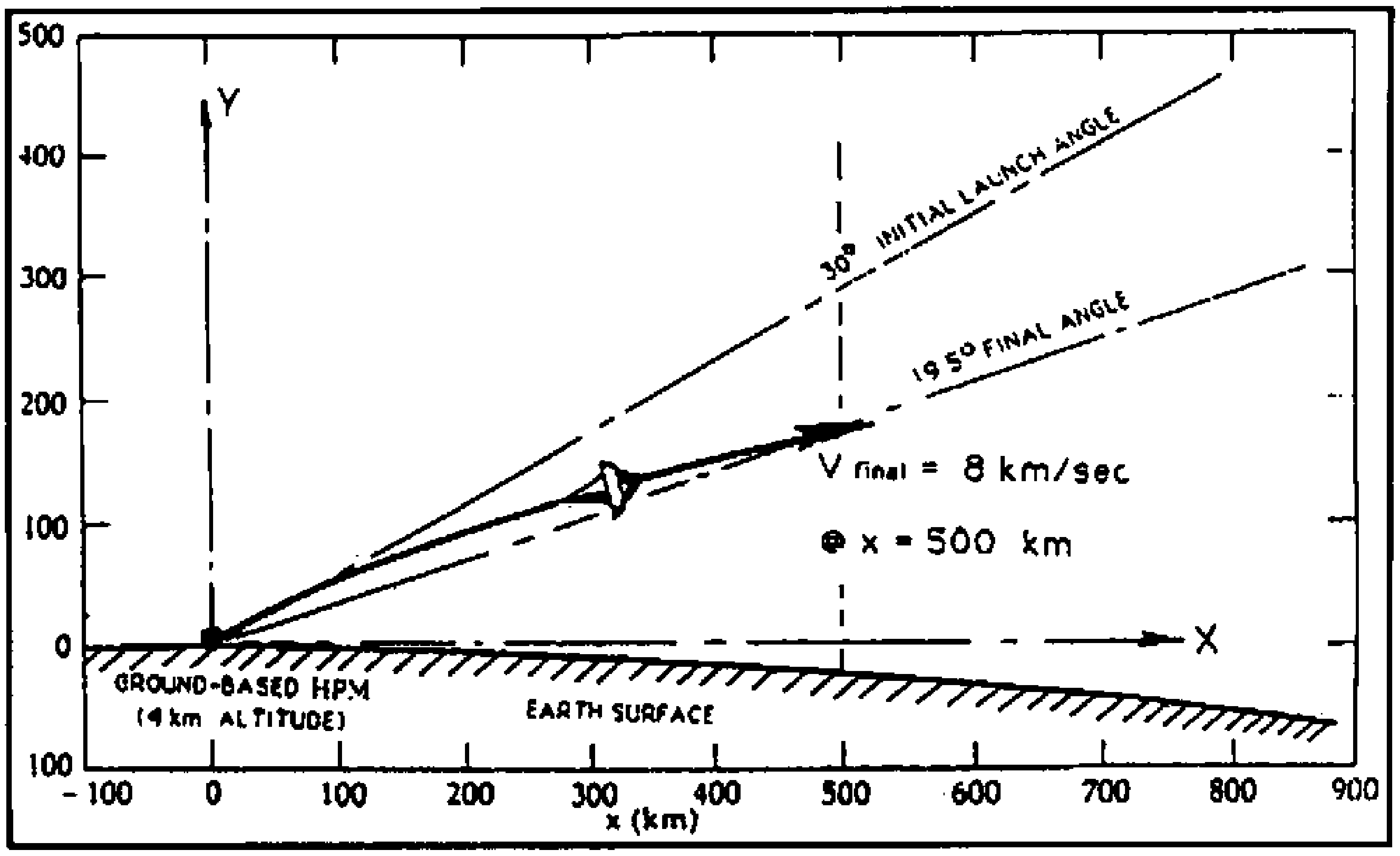

Figure 5. Direct HPM launch to orbit (no relay satellite).

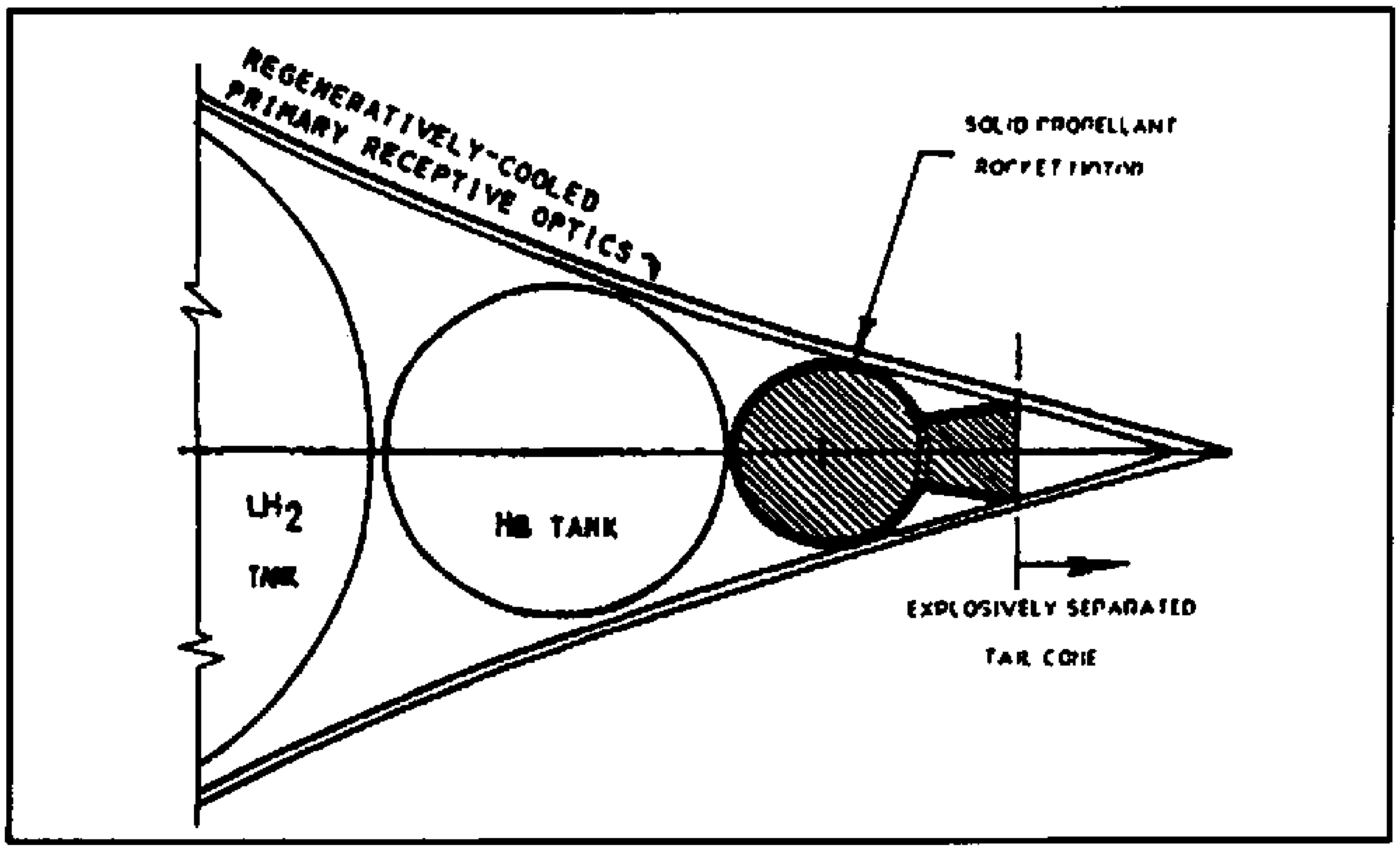

Figure 6. Chemical "kick" rocket option for orbit circulaization.

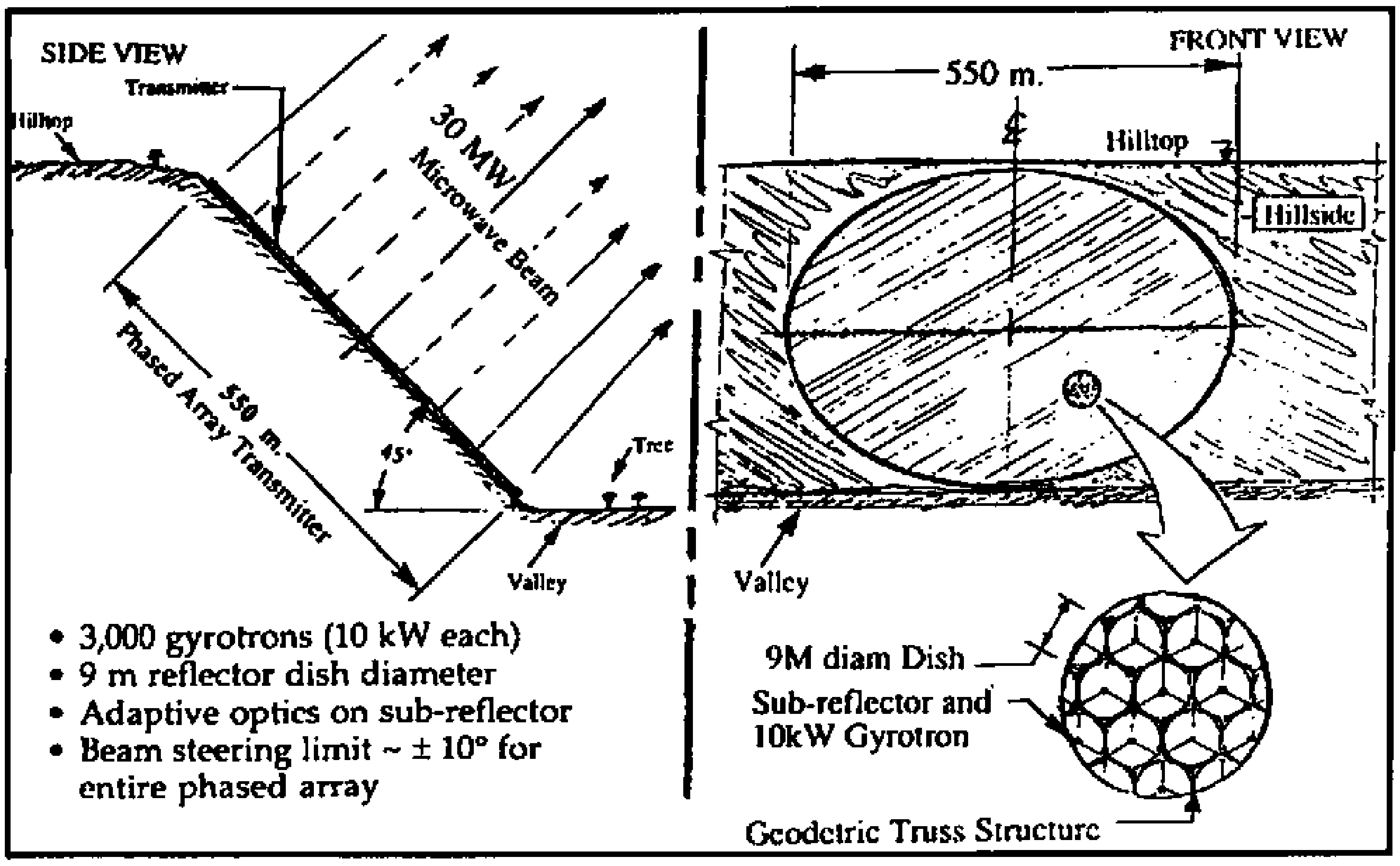

Figure 7. 30 MW microwave launch station (4 Km altitude site).

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