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 vehi-
cle. It would also use advanced beamed power
techniques, including one developed under SSI
sponsorship by Professor Yuri Raizer and Lek
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 tech-
nical risk. The second is a large enough
demand for launch services to make the invest-
ment 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 pay-
load 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. Reduc-
ing 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 prop-
ulsion means less propellant, minimal tank-
age penalty and lighter engines.

Airbreathing HPM Pulsejets

For maximum performance in accelera-
tion, future engines designed for transatmo-
spheric spacecraft are likely to encompass
both airbreathing and rocket elements, and
transition through various propulsion modes
as a function of flight mach number and alti-
tude. 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).
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 propagative 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 embedded 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).](image)

**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 carbide 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 airbreathing 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 coastes 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 **S/S 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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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 ultrahigh data rate transfer; Earth resources satellite capable of visible, infrared, ultraviolet and radar sensor wide area observation; cellular phone communication and relay stations; space-based virtual reality; wandering asteroid/planetoid threat detection and monitoring; exploration for extraterrestrial resources; 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 $15 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 spacecraft.

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


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

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

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

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