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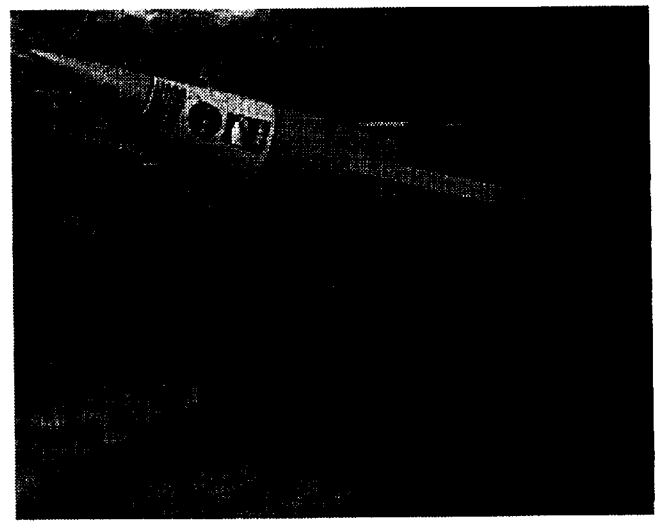
Access to Space:

Beyond the Next Generation



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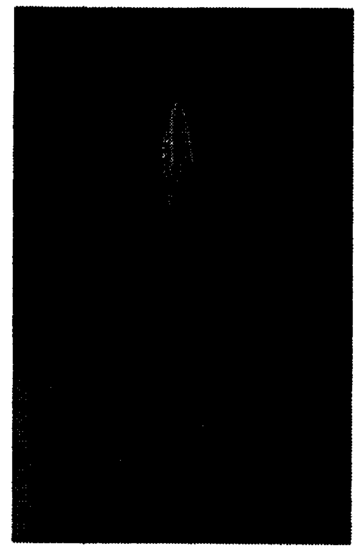
Single Stage to orbit:
Pros and Cons



DC-X rocket in flight

Pro:

- Only one stage is single vehicle, not two: development cost is half
- No mating of stages is required; turn-around time is minimal
- The main cost of a launch is not the fuel cost, it is the operations.
- Simplicity.

Con

- Mass fraction!!!!

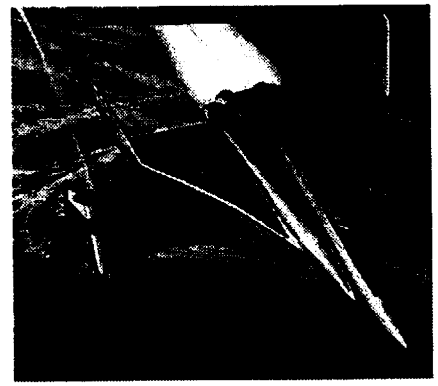
90% (or more) of lift-off mass must be fuel!

- Must have very light structure
- Must have very efficient engine
- No margin: if structural mass grows by a few percent, playload decreases to zero!
- Vehicles has very large lift-off weight

Vehicle must be optimized for entire trajectory

Two Stage to orbit:

Pros and Cons



Concept for two-stage reusable launch vehicle

Pro:

- **Far better mass ratio**

Mass ratio is exponential function of delta-V required: two stages each with half of the delta-V have better mass ratio than one stage with twice the delta-V

- **Each stage optimized for its part of trajectory**

Bottom stage needs high thrust; does not need high specific impulse (mass ratio not critical for bottom stage)

Top stage needs high performance, lower thrust

Only top stage needs thermal protection for orbital reentry

Bottom engine expansion ratio can be tuned to best performance at atmospheric pressure, top for vacuum

Con:

- **Must develop two vehicles**
- **Mating of stages is required; turn-around time is increased**

Jet engines

Why not carry only the fuel, and use air from the atmosphere for the oxidizer?

For a oxygen/hydrogen system, oxygen is 92% of the fuel mass

A jet engine can only be used when the vehicle is in the atmosphere, but could be used for much of the initial acceleration of the vehicle.

Types of Jet engines

Orbit requires a speed of about Mach 25

Turbojet engines (used in commercial jets, most military jets) work up to about Mach 3.

Ramjet engines can be used to Mach 5 (but does not work at subsonic speeds)

At higher Mach numbers the fuel consumption increases faster than thrust is generated.

Above Mach 5, supersonic combustion is needed: a

scramjet engine

Scramjets work from Mach 4 to Mach 10-12 (not tested)

- A possible space launch vehicle could use a Rocket-based Combined Cycle Engine (RBCC). In this an airbreathing ramjet/scramjet engine is combined with a rocket engine. The vehicle is accelerated by the rocket engine from zero speed up to the speed where the ramjet can be used. The ramjet operation then takes over, and transitions to scramjet operation up to speeds of Mach 10 to 12. Above this speeds the rocket engine takes the vehicle into orbit.

Why not a Scramjet-based Engine?

Pros

- Scramjet does not need to carry oxidizer, which is the heaviest part of the fuel
  In theory this reduces the mass ratio of the vehicle

Cons:

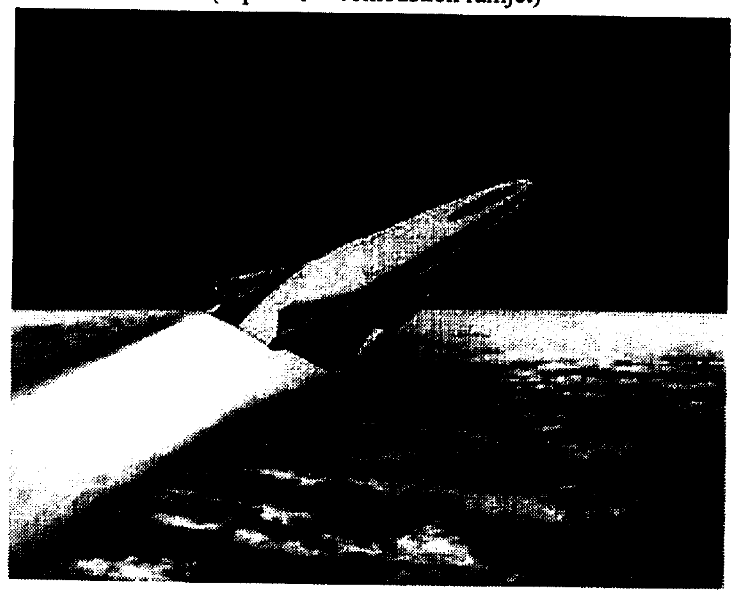
- LOX is very cheap and dense
- Jets have much lower thrust to weight ratio than rockets-- heavier engine is needed to produce the same thrust as a rocket
- For a SSTO design, scramjet must be carried all the way to orbit even though it can only be used to Mach 10-12
- Scramjets are expensive to develop & build;

  Rocket engines are cheap and available off the shelf
- Scramjets have not yet been demonstrated to produce postive thrust
- intense thermal problems due to operation at hypersonic speed for long duration

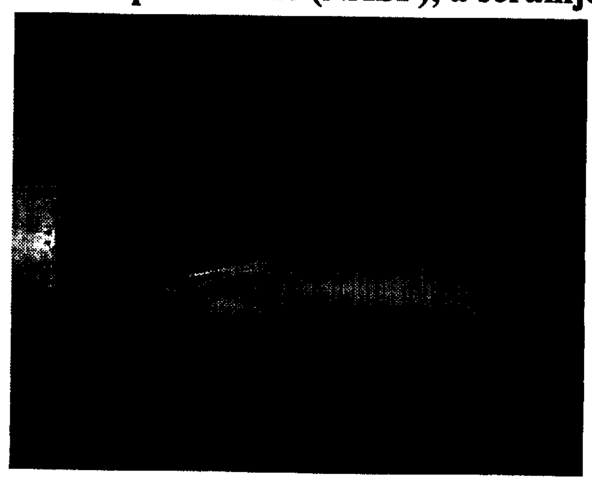
  Complexity: scramjet-based system must have ramjet, scramjet, and rocket modes of operation

Scramjet

(supersonic combustion ramjet)



Design concept for National Aerospace Plane (NASP), a scramjet-propelled launch vehicle

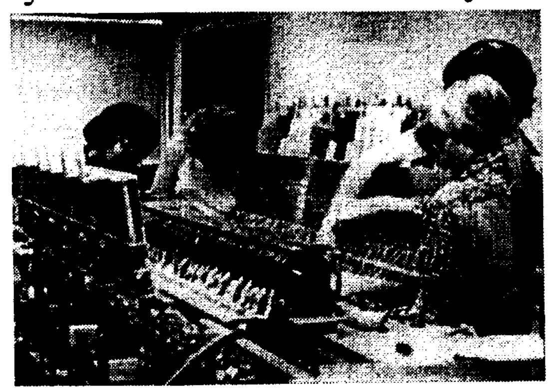


test of NASP inlet

Direct impulse Launch Systems:

- Electromagnetic mass-driver
- Light-gas gun
- Cannon
- Ram-accelerator

Concept: use a ground-based launch system to accelerate directly to orbital velocity



prototype mass-driver built at Space Studies Institute

Pro:

- Minimum vehicle-- propulsion remains on ground
- Low cost-- get to orbit for the cost of electricity (about $0.50 per kilogram)
- Possible way to send large amounts of bulk materials for space construction into orbit cheap
- Light-gas guns have been demonstrated to velocities approaching orbital speed

Con:

- Must penetrate atmosphere at orbital speed!

Projectile long and slender; nose portion ablates

Requires mountaintop and/or tower launch

- Acceleration of ~ 1000000000 g needed

Too high for humans! May be possible for bulk materials

- Requires rocket motor for orbital insertion
- High peak-power pulsed-power system needed
- Sonic boom

- Very tough to make this work on Earth! (but may be good for a lunar launch system)
- Possible to use this as a booster stage in conjunction with a different system (SSTO, laser, tether)

Use of tethers in space

A tether is a long, flexible string

The natural configuration of a tether is vertical.

The mass on the higher end is moving faster than orbital velocity

- If this mass is a satellite, then when it is released it will be tossed into a higher orbit
- Can be used as a reusable orbital transfer stage

The mass on the lower end is moving at less than orbital velocity

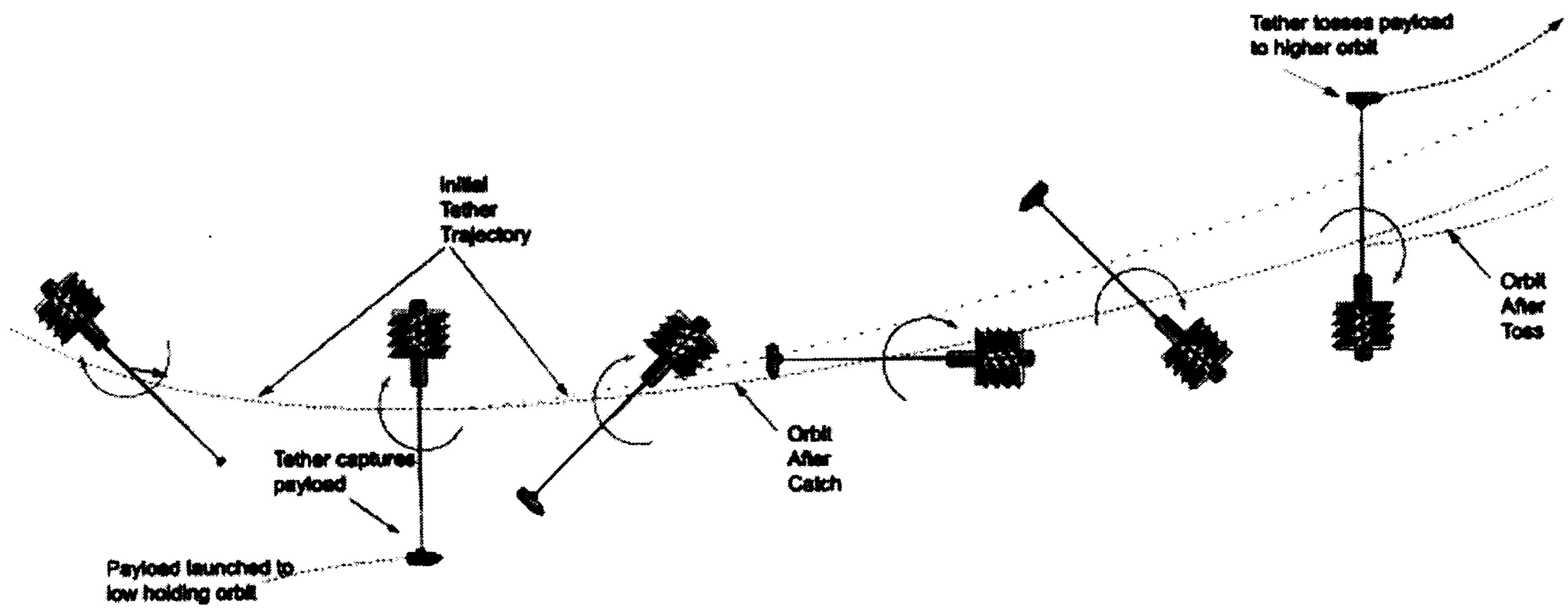
- If this mass is released, then it will be dropped into a lower orbit
- Can be used to re-enter (for example, to drop a capsule, or to dispose of space-station waste)
- If a rocket rising up from the Earth makes a rendezvous with the lower end of a tether, it will require less than orbital velocity
- Can be used to reduce the energy required to reach orbit

Other types of tethers

Rotating tethers (used for artificial gravity)

Rotating tethers (used for propulsion)

Electrodynamic tethers



Boeing/TU Concept for use of a rotating tether to "catch" payload from lower orbit and "toss" it to higher orbit

Can be used even if the "lower" orbit is a suborbital ballistic arc from the ground:

" a hypersonic airplane would take off from a conventional airport and carry a payload up to an altitude of 100 km and a speed of about Mach 10-12. The airplane would rendezvous with the tip of a rotating tether facility in orbit, and hand the payload over to the tether. The tether would then pull the payload up into orbit.."

From http://www.tethers.com/MXTethers.html

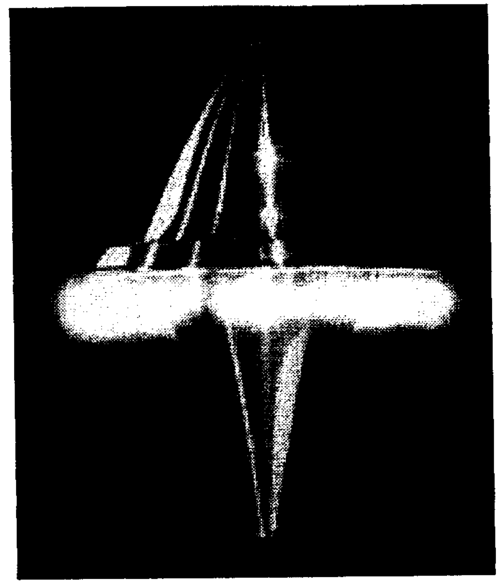
Laser-launch system

Concept: leave the energy production on the ground. Laser beam sends energy to the rocket

Many different versions:
Laser-thermal rocket (laser-heated hydrogen rocket)
Laser ablation rocket ("laser-supported detonation")
Air-breathing laser rocket

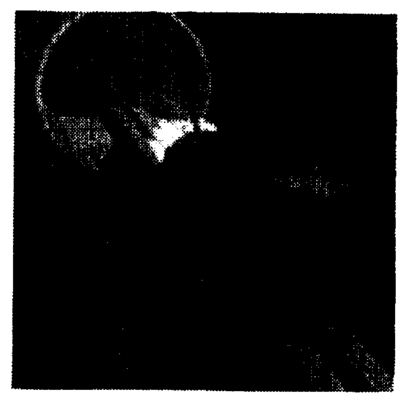
Problem: needs many megawatts of laser power to launch even very small payloads

Laser-boosted rocket in initial air-breathing phase (schematic)



Laser-boosted rocket test

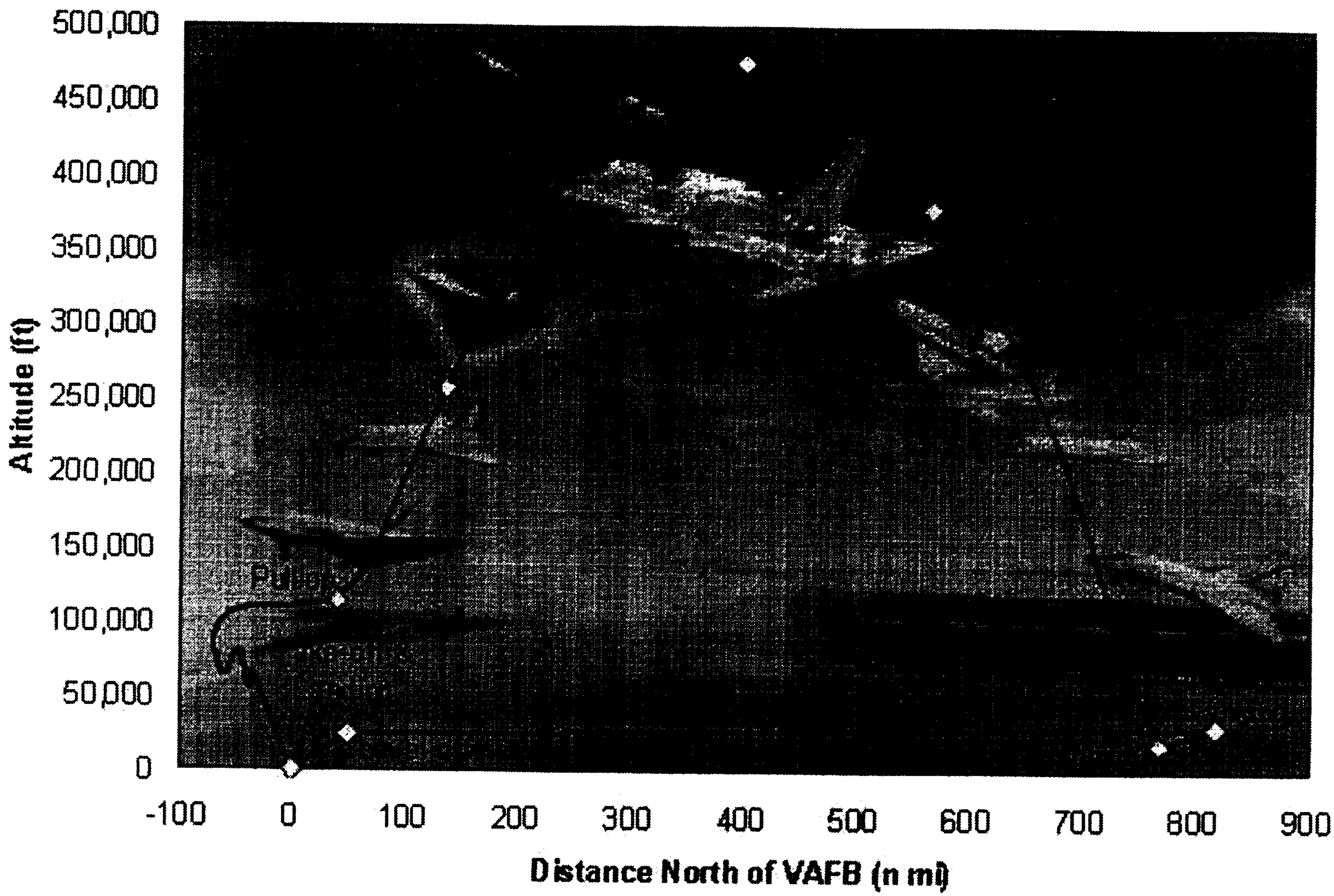
Launch Assist Systems



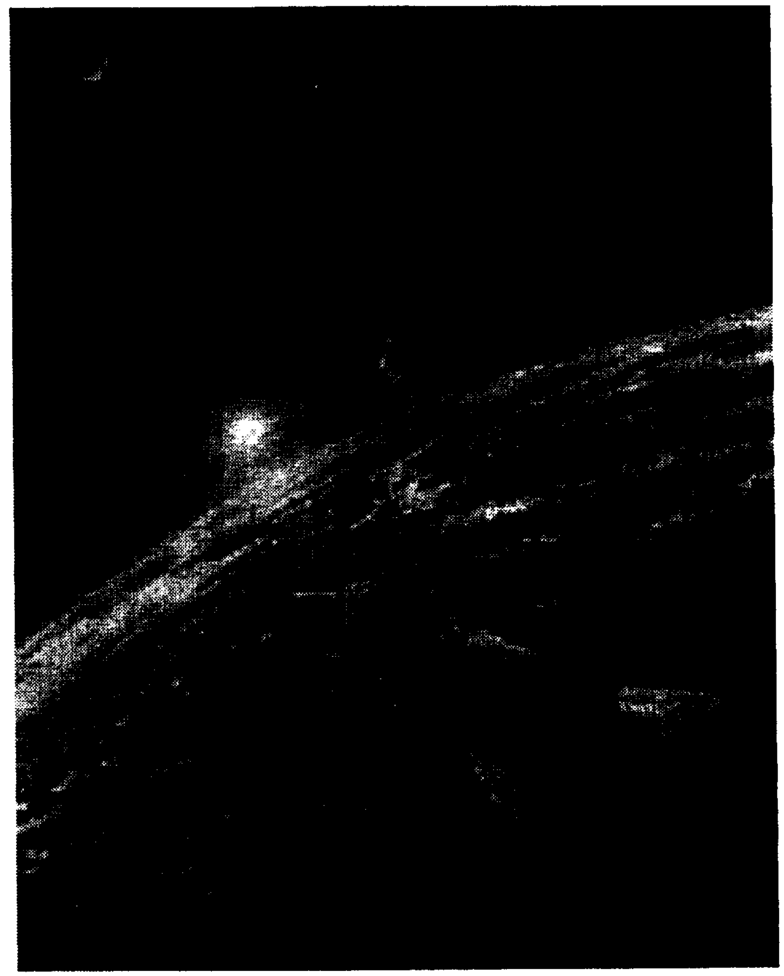
Launch-assist systems such as an electromagnetic track ("maglev") or a pressurized-piston launch assist device can significantly improve the payload of a single-stage-to-orbit vehicle by giving the vehicle an initial velocity without burning rocket fuel

Pioneer Rocketplane Concept

In the "Pioneer" concept, the launch vehicle (shown in black) is launched on a jet engines with empty tanks. It loads the rocket fuel with mid-air refueling. (Image from http://www.rocketplane.com/)



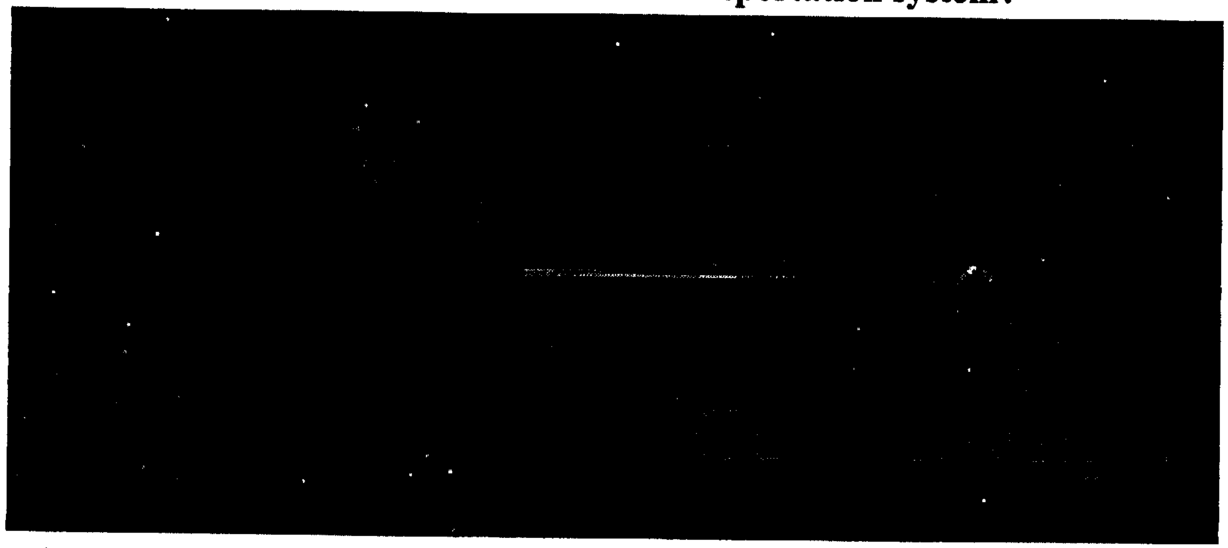
The prototype of the Pioneer vehicle does not go into directly into orbit, but instead makes a suborbital "hop." At the peak of its trajectory, above the atmosphere, it releases a satellite. A small solid rocket motor takes the satellite into orbit, while the launch vehicle returns to Earth. (Image from http://www.rocketplane.com/)



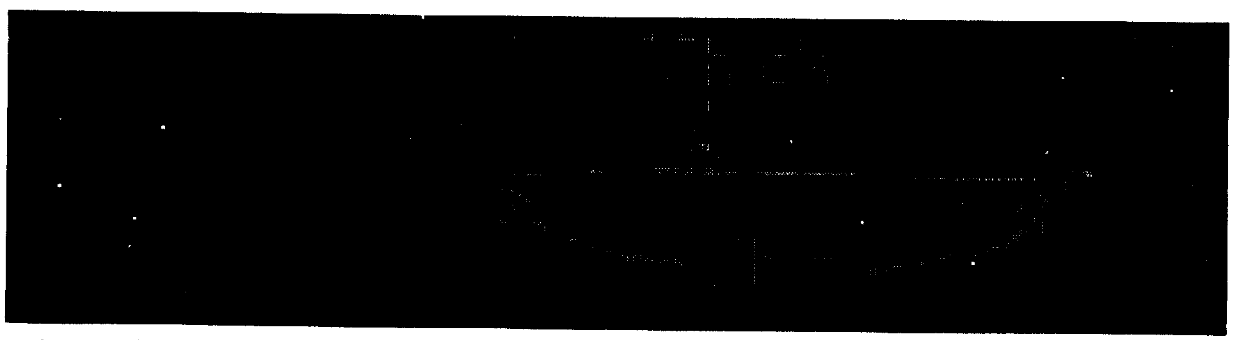
A small solid rocket motor takes the satellite into orbit, while the launch vehicle returns to Earth.
(Image from http://www.rocketplane.com/) fuel

The Geosynchronous Skyhook:

The ultimate earth-to-orbit transportation system?



The skyhook is a cable that extends from geosynchronous orbit both downward and upward. At geosynchronous orbit, the force on the mass is zero. A counterweight pulls the cable into tension



The maximum tension on the cable is at the center. To minimize cable mass, a skyhook cable is tapered in both directions. Even with an optimum taper, the mass required for a skyhook is unrealistic with existing materials.

Geosynchronous skyhook

Pro:

Earth surface to Geosynchronous orbit transport by elevator at the cost of electric power
(about fifty cents per pound)

Con:

require a materials technology that is not available (yet)!
(requires fullerine fibers or other material with strength to weight ratio about ten times higher than best current materials)

LEO satellite collision hazard
Space debris hazard-- requires redundant fiber design.
Tether dynamics issues and atmospheric interaction issues need to be solved
"Engineering" details of how to use a skyhook to reach orbit are still unclear

Science fiction (today)

Summary:

Access to orbit is expensive,
but there are new ideas for space access that may make it lower in cost