S38-31

38705

p 5

N91-71232

A LUNAR MASS TRANSPORTATION SYSTEM; T. A. Heppenheimer, Center for Space Science, Fountain Valley, California.

In 1950, Clarke (1) suggested the use of electromagnetic accelerators in space transportation. In 1974, O'Neill (2) proposed that such accelerators be used for large-scale lunar material transport. Since then, further work has aimed at a preliminary engineering specification of such a system. The present abstract reports results which are to be published in greater detail elsewhere (3).

Requirements: The proposed approach envisions the establishment on the lunar surface of an electromagnetic accelerator or mass-driver, which operates using electricity from a nuclear or power-satellite source, thus avoiding the use of rockets. Throughput is some 10^6 tons/year. Individual packets of material are accelerated to lunar escape, 2400 m/sec, with launch accuracy of 10^{-3} m/sec or better. Payloads' flight is entirely ballistic, without midcourse guidance; they arrive at a catcher vehicle with dispersion of 100 meters or less.

Approach: The selected accelerator concept involves tracked, magnetically-levitated payload carriers ("buckets"), accelerated by linear synchronous motor (Fig. 1). Cross-track velocity is controlled by providing an accurately aligned section of track prior to payload release, along which cross-track bucket motions damp out via a passive bucket suspension. Along-track velocity is controlled using laser doppler. Payload release occurs by withdrawal of a restraining support. The catcher is a large rotating bag of Kevlar fabric, located at the L2 libration point. When the catcher is full, onboard propulsion systems permit it to carry the payload to the delivery site. These systems involve the Rotary Pellet Launcher (RPL), also proposed by O'Neill (2): a rapidly-rotating tube, ejecting pellets of rock at high velocity.

Magnetic Levitation: The buckets are suspended by paired superconducting coils, which straddle aluminum flanges along the length of the track. The coils are of opposite polarity, so the suspension is of the "null-flux" design (4). The coils are cooled by liquid helium fed from a dewar; cold-gas boiloff is regeneratively circulated within the coils, then stored in an accumulator. Typical parameters: coil diameter, 15 cm; coil-track separation, 2 cm; current, 6200 amp-turns. For the track flanges, typical dimensions are 20 cm wide, 0.5 cm thick.

Bucket: The bucket proper contains a main superconducting magnet (30,000 gauss), a dewar and accumulator, and payload supports. Mass, approx. 10 kg exclusive of payload and suspension coils. Payloads are 10-20 kg lumps of lightly sintered soil and rocks. Prior to launch, each bucket undergoes a servicing operation, consisting of a dewar refill, accumulator tapoff, and the placement of a payload into the support.

Tracks: The track is E-shaped in cross section, 70 x 35 cm, of aluminum, with mass 27 kg/meter (under 1000 tons for 30 km total length). The first 10 km is the main acceleration section, where the bucket is accelerated at 300 m/sec^2. The next 1 km is a fine-adjust section where accelerations of 1 m/sec^2 are applied. The next 1 km is a drift section, where the bucket decelerates at under 10^{-2} m/sec^2 due to electromagnetic drag. Release of payload occurs within the drift section. Then there is a section of 3 km in which the bucket is decelerated, again by linear synchronous motor; and finally a 15-km return section. The bucket is suspended or levitated by electromagnetic lift, once it reaches a velocity of a few tens of meters per second. Thus, for initial acceleration it must be supported by a wheeled dolly, until it gets up to flying speed.

Laser Doppler: The proposed system has (integration time) (measurement accuracy) = 10^{-6} meters. For example, integration time of 10^{-3} sec permits velocity determination to an accuracy of 10^{-3} m/sec.

Bucket Frequency Response: The supporting null-flux coils are attached to the bucket with support arms which provide a mechanical spring-dashpot coupling. Parameters of the suspension and coils are chosen to provide good frequency response so that the cross-track motions are damped within the 1 km drift section. The bucket proper has characteristic frequency approx. 10 radian/sec; the coils, 100 rad/sec. Damping is near the critical value.

Track Alignment: Required track alignment is found by Bode-plot analysis, under the condition, max. crosswise velocity at release = 10^{-3} m/sec. Then, over track lengths of 24 to 240 meters, allowable misalignment (in the fine-adjust and drift sections) is 10^{-4} meters. This may be achieved using an optical alignment system similar to that employed at Stanford Linear Accelerator Center (5). In that system, track-mounted Fresnel zone plates focus a laser beam to a point; photodetectors locate the point and scan across it. The center of the point is found automatically and reproducibly, to an accuracy of 25 microns. Hence, the displacement of a track location is found to this accuracy. The track is to be mounted upon piles driven into the regolith, spaced every 10 meters, and supported at each pile by a screw-jack mount driven by a worm-wheel actuator. (See Figure 2).

Away from these critical sections, track alignment is associated with use of standard alignment systems used in civil engineering. A misalignment of several times 10^{-3} meters is permissible. The criterion is that the ride be not too rough.

Payload Restraint: During the initial acceleration, the payload is rigidly supported by metal plates. Upon entering the fine-adjust section, these plates are pulled away by springs, and the payload is restrained only by a mechanical "finger" which presses it down from above. The spring-actuated withdrawal of the finger constitutes the event of launch. The bucket follows the lunar surface curvature so the payload accelerates upward at one lunar g, $1.5\ m/sec^2$.

Other Mass-Driver Characteristics: Cycle rate is 3 to 4 launches per second. Linear synchronous motor parameters are as in (2). The track is housed within a lightweight aluminum tunnel, to aid in thermal control. Power required is some 200 megawatts, initially supplied by nuclear plant. The first solar power satellite built in space then is maneuvered to the lunar L1 libration point, 60,000 km Earthward of the lunar nearside, to provide gigawatts of power and allow a major expansion in system throughput. It is kept at L1 as a libration-point satellite (6), beaming its power to a lunar-surface rectenna.

Payload Trajectory: The payloads fly ballistically to the catcher, located at the L2 libration point, 60,000 km behind the lunar farside. There are three reasons for selecting L2: The mass-driver can be sited on the lunar nearside. Also, use of L2 allows the most liberal launch-accuracy requirements consistent with catching in deep space, away from lunar gravity. Also, the payload stream is directed away from space traffic and is not a hazard to navigation. The payloads arrive at L2 at approx. 200 m/sec. It is not possible for a payload launched from the lunar surface to arrive at L2 with near-zero velocity (7).

Catcher: A variety of active catcher concepts have been proposed, wherein incoming payloads are automatically tracked and small catching modules are opened or maneuvered to receive them. Such concepts appear open to challenge, on grounds of mechanical complexity, lack of reliability, lack of fail-safe operation, or susceptibility to damage from payloads. The preferred concept is a passive catcher, designed as a mechanical analog of the radiation blackbody cavity: payloads can enter, but material once caught cannot escape.

The principal element is a bag of 10-ply Kevlar fabric. (9-ply Kevlar stops a .44 magnum bullet fired point-blank.) The bag is approx. 100 meters diam. by several hundred meters long; mass, $2\ kg/m^2$. The mouth of the bag is supported by a rim which mounts a grid of cables. The payloads break up on striking the grid, thus protecting the bag. The bag rotates, holding caught material by centrifugal force. The rim contains crew quarters, a nuclear power plant and its radiator, and Rotary Pellet Launcher (RPL) thrustors.

RPL: The RPL provides both stationkeeping against the payloads' momentum and propulsion to transport the filled catcher. Typical parameters: rotation rate, 2500 rpm; tube length (axis to tip), 50 ft.; material, Kevlar; thickness, 4" tube OD at tip, tapering exponentially to 40" OD at axis; mass, 38,000 lbs;

A LUNAR MASS TRANSPORTATION SYSTEM

T. A. Heppenheimer

Figure 1

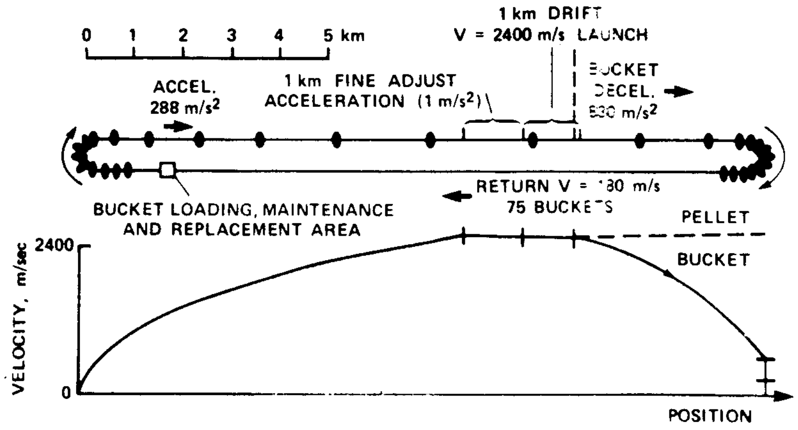
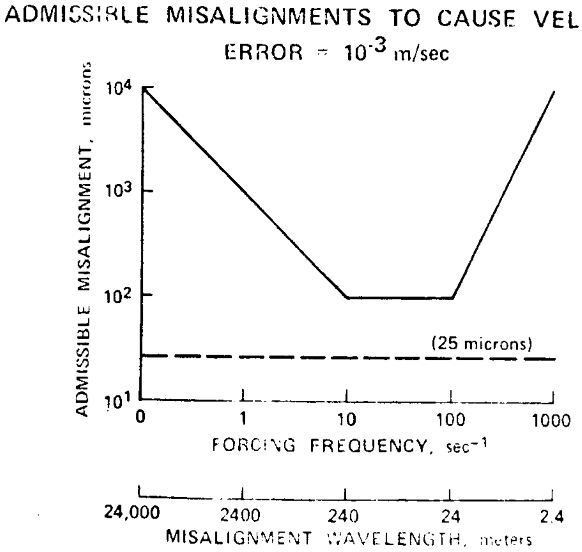


Figure 2



pellet mass, 10g; specific impulse, 405 sec.; thrust, 369 lbs.; power, 7.2 megawatts. In this design we work at 60% of the yield strength of Kevlar; max stress due to acceleration of pellet is under 7% of yield stress. Three RPL's are required per catcher.

RPL Injector: The injector admits pellets to the tube in such a manner to produce a collimated exhaust stream. Pellets are fed axially into a feed tube, which points outward and rotates with the RPL tube. A cam-driven gate ensures only one pellet is at the end of the feed tube. This pellet presses and rubs against a fixed circumferential restraint; but there is a hole in the restraint through which the pellet is admitted into the RPL tube. The restraint is concentric with the RPL rotation axis. By turning the restraint, one controls the direction of the RPL exhaust. A diagram of the injector is in reference (3).

Environmental Hazard: The RPL pellets represent artificial meteoroids. It is expected we could eject 5 x 10^{15} pellets (5 x 10^{9} tons) before the hazard from these pellets exceeds one impact per square kilometer every ten years.

General Comment: The RPL concept opens up the possibility of a solar-powered deep space transporter which uses as propellant, not hydrogen from the sea or cesium from the earth, but ordinary dust and rock from the bodies of the Solar System. The mass-driver also may have application as a reaction device. These systems may go far to overcome the limitations attendant upon any proposal to open up the Solar System using rockets.

References

1. Clarke, A.C., J. Brit. Interplanetary Soc. 9, 261 (1950).

2. O'Neill, G. K., Phys. Today 27, 32 (1974).

3. Heppenheimer, T. A., J. Brit. Interplanetary Soc., in press (1976).

4. Powell, J. R. and Danby, G. R., ASME Paper 66-WA/RR5 (1966).

5. Hermannsfeldt, W.B., etal, chapter 22 of The Stanford Two-Mile Accelerator, R.B. Neal, editor. W. A. Benjamin, Reading, Mass. (1968).

6. Farquhar, R. W., Astronautics and Aeronautics 7, 52 (1969).

7. Heppenheimer, T.A. and Porco, C.C., Icarus 30, in press (1977).