Capture-Ejector Satellites

Ian O. MacConochie,* Charles H. Eldred,† and James A. Martin‡
NASA Langley Research Center, Hampton, Virginia

Abstract

IN this paper, a satellite in the form of a large rotating rim that can be used to boost payloads from low-Earth orbit to higher orbits is described. The rim rotates in the plane of its orbit such that the lower portion of the rim is traveling at less than orbital velocity, while the upper portion is traveling at greater than orbital velocity. The ascending transport arrives at the lowest portion of the rim at less than orbital velocities and discharges its payload for attachment to the rim's perimeter. The payload remains on that portion of the rim until it reaches its highest point, where it is released on a trajectory for higher orbits. Transfers from a high- to a low-Earth orbit, or entry, are accomplished by employing the reverse procedure. When using the Capture-Ejector Rim System on orbit, significant reductions in the size and number of flights for the delivery transport are possible.

Contents

Several proposals have been made for large towers or rotating spokes, which could serve as gravity ladders.[1,2] Their purpose is to reduce propulsion requirements for spacecraft traveling between the Earth and various orbits.

Instead of permanent towers or rotating spokes, the authors propose a plain rim, referred to herein as a Capture-Ejector Rim. An advantage of the rim over a rotating tower (or spokes) is the relative ease with which phasing for landing or takeoff from the rim can be accomplished.

For purposes of illustration, a rim is depicted showing velocities relative to a radius to the Earth's center (Fig. 1). Rim velocity is maintained by using electric drives or efficient jets. Assume that the correct circular velocity for the center of mass of the rim is 25,500 ft/s and that the rim is rotating at a speed relative to its center of 3000 ft/s. For these assumptions, the top of the rim is traveling at 28,500 ft/s while the lower portion of the rim is traveling at 22,500 ft/s. In order for an ascending spacecraft to attach to the bottom of the rim with nearly zero relative velocity, it must be on a ballistic trajectory—a trajectory for which the apogee velocity is 22,500 ft/s. After attaching to the rim, the spacecraft is carried to the top of the rim where it is released, having gained velocity in the amount of twice the rim speed—6000 ft/s.

The dramatic effect on the weight of the ascending booster, when using a Capture-Ejector Rim for supplementary velocity, is shown in Fig. 2. For example, if the release velocity is 28,500 ft/s, a single-stage launch vehicle can be reduced from a 10,000,000- to 2,000,000-lb liftoff weight. These values apply to a 65,000-lb payload delivered to the lower portion of the rim by the launch vehicle.

Many technical and economic aspects of the Capture-Ejector system would have to be resolved before serious consideration could be given to its use. The following calculations are related to the system. First, consider the simplest problem: the velocity limit in the rim while it is rotating with no payload attached. Summing forces in the radial direction for a rim element gives

$$\Sigma F = (W/g)a - 2\sigma A \sin(\mathrm{d}\theta/2) = 0$$

where W is the weight of the rim element, a the centrifugal acceleration of the element, σ the stress in the rim cross section, $\mathrm{d}\theta$ the included angle the element makes with the geometric center of the rim, and A the rim cross-sectional area.

Now, substituting for W the product of rim density (ρ) times the volume of the segment, and replacing $\sin(\mathrm{d}\theta/2)$ with $\mathrm{d}\theta/2$ for small angles and V^2/r ($V=$ velocity, $r=$ radius) for a, the preceding becomes

$$(\rho A r \mathrm{d}\theta/g)(V^2/r) - 2\sigma A(\mathrm{d}\theta/2) = 0$$

Canceling terms and solving for rim velocity yields

$$V = \sqrt{\sigma g/\rho}$$

For the assumptions of a plain rim with no payload attached, the results show that the rim velocity achievable is independent of the rim radius and depends only on the specific strength of the rim material from which the rim is made. For a composite of aramid fiber, applying current technology, a rim speed of about 3000 ft/s is theoretically possible. For the real case, allowances would have to be made for stress increases in the rim, such as from the dynamic loads during payload attachment. This would necessitate the application of a design factor and the reduction in the allowable rim speed.

For any spacecraft (or spacecraft plus personnel transfer) there will be a maximum acceptable g level. For the Shuttle, the limit for the system is 3 g's, a value that is approached but not sustained. The required radius for a Capture-Ejector Rim for a 3-g limit and 3000-ft/s speed is 93,167 ft (17.6

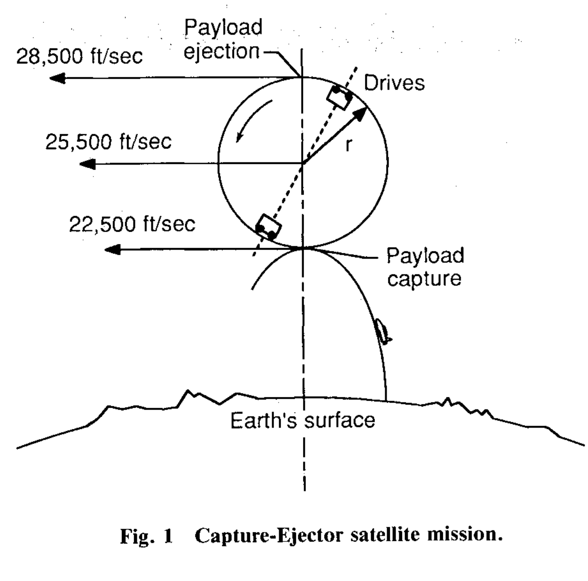

Fig. 1 Capture-Ejector satellite mission.

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*Aero-Space Technologist, Vehicle Analysis Branch, Space Systems Division. Senior Member AIAA.

†Assistant Branch Head, Vehicle Analysis Branch, Space Systems Division. Member AIAA.

‡Aerospace Engineer, Vehicle Analysis Branch, Space Systems Division, Associate Fellow AIAA.

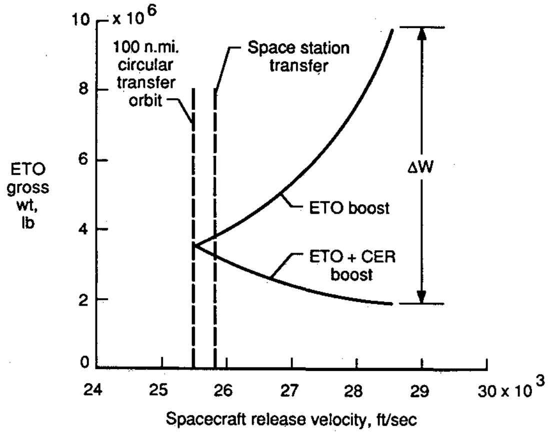

Fig. 2 Earth-to-orbit launch vehicle size vs perigee velocity with and without a Capture-Ejector satellite.

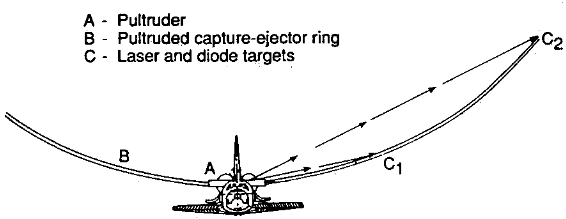

Fig. 3 Capture-Ejector satellite manufacture.

miles). This value is obtained from the relationship

$$a = V^2/r$$

The preceding equations give nearly exact answers for a rotating rim transferring an infinitesimally small mass. In the real case, a spacecraft of finite mass, upon contact with the rim, will start to distort the rim; the distortion of the rim from a circle proceeds until the radial components of the rim tension forces are in equilibrium with the incremental centripetal force produced by the added mass of the spacecraft being transferred. At the same time, the rim/spacecraft combination must assume a new center of rotation, which is at the combined mass center of the two. The eccentricity of the rotating rim is given by

$$e = m_{sc}/(m_r + m_{sc})$$

where the mass of the rim, m_r, is usually much greater than the mass of the spacecraft, m_{sc}, making the eccentricity relatively small. When eccentricity is multiplied times rim radius, the distance between the geometric center of the rim and the center of rotation of the combined masses is obtained.

For the transfer of a 65,000-lb spacecraft at a 3-*g* limit while imparting a 6000-ft/s velocity, the rim would weigh an estimated 3,860,000 lb. This value is based on a material strength for the rim of 200,000 lb/in.^{2}, a cross section of 10 in.^{2}, and a density of 0.055 lb/in.^{2} It is assumed that the Capture-Ejector Rim is manufactured on orbit, as shown in Fig. 3, using a continuous process.[3] If 150,000 lb of resin and fiber reinforcement is carried on each flight of a heavy-lift vehicle, approximately 26 flights would be required to fabricate the rim.

References

[1]Pearson, J., "The Orbital Tower: A Spacecraft Launcher Using the Earth's Rotational Energy," *Acta Astronautica,* Vol. 2, 1975, p. 785.

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[3]Thompson, V. and Bradley, R. J., "Pultrusion of Advanced Composites," SME Paper EM76-415, 1976.