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A SCHEME FOR TRANSPORT OF LUNAR MATERIALS TO UTILIZATION SITES IN EARTH ORBIT; Gerald W. Driggers, Southern Research Institute, Birmingham, Alabama.

Use of lunar resources at some earth orbit location implies transportation by some means of raw or processed materials. Large scale use of such materials will dictate an inexpensive operation in order to minimize overall cost. One method to accomplish this has been proposed by O'Neill wherein small masses would be ejected in large numbers from the moon and collected in space (1,2). Electromagnetic fields would be used to accelerate "buckets" to near lunar escape velocity where the material would be released and the buckets "recycled" for new payloads. This paper is not intended as a review of pros and cons for this proposal, but as a medium for presentation of an alternate technique. Each approach has particular advantages and other competitive possibilities certainly exist.

Briefly, the scheme presented here uses a pressurized "gas gun" called a Large Pneumatic Accelerator (LPA) to eject material from the moon and a small Rendezvous and Retrieval Vehicle (RRV) to capture the ejecta and locate it as required. Individual large payloads (say,100,000 pounds or greater) would be launched as opposed to several launches of smaller masses. The LPA would eject the material with velocity (speed and direction) conditions that have a known statistical distribution. Tracking would be accomplished for a period after launch to establish an ephemeris allowing state vector prediction in time and ultimate RRV rendezvous. The speed imparted to the mass could be controlled such that a two or three standard deviation high dispersion would be the exact required velocity. Thus, 95 percent plus of the masses would require velocity makeup within known bounds. Payloads outside established bounds (velocity, path) would simply be neglected.

The parameters of the LPA have been looked at in a cursory fashion to establish preliminary estimates of size and weight. Simplifying assumptions such as constant pressure and no frictional forces are inherent to the analysis. A blow-down tank system was assumed with multiple injection ports along the LPA tube (termed the booster). The gas dynamics of accelerating the projectile to about 7800 ft/sec in a tube were not addressed. The capability to accelerate small masses to hypersonic velocity in tubes has been demonstrated.

The effect of payload average acceleration on booster tube length is shown in Figure 1. If extended on to 1000 g's (not an unreasonable number), the tube length is reduced to about 945 feet. For an average acceleration of 500 g's and a booster tube diameter of 240 inches, an average pressure of less than 1500 psi will accelerate 130,000 pounds to escape velocity. The relationship of pressure and payload mass is shown in Figure 2 for those parameters. If a smaller diameter tube is desirable, the operating pressure can be increased accordingly or the tube lengthened. The governing equation is

$$P_b = 2\, m_{PL}\, V^2/\pi l_b d_b^{\,2} \tag{1}$$

where

P_b = booster tube pressure
m_{PL} = payload mass
V = desired exit velocity of payload
l_b = booster tube length
d_b = booster tube diameter

An interesting consequence of Equation (1) is that the product $P_b l_b d_b^{\,2}$ is a direct function of payload mass. These parameters, coupled with simple membrane theory for pressurized tubes, lead to the following result

$$m_b = \frac{\rho}{\sigma} V^2 m_{PL} \tag{2}$$

where

m_b = booster tube mass
ρ = tube material density
σ = working stress of tube material
V = desired exit velocity of payload
m_{PL} = payload mass

For a 130,000 pound payload, a moderate strength-to-density material (say 50,000 psi/1.40 gm/cm^3) will yield a tube weight of about 3,000,000 pounds and a wall thickness of 3.4 inches. Advanced composites in use today for pressure vessels and solid rocket motors can cut this weight and thickness by a factor of two.

Holding tank requirements were explored in an idealized parametric sense. Scavenging a substantial percentage of the gas looks feasible with some careful design work near the tube exit. Ideally, 100 percent of the working gas could be contained and reused. The holding tank parameters are not very sensitive to such design details considering the total volume of the booster tube. The tank weight is determined by length (l_t) and wall thickness (t_t) which are functions of holding pressure (P_t), booster tube final volume, booster tube pressure, tank mean radius (r_t) and tank material working stress (σ). The variation of l_t and t_t as a function of holding pressure is shown in Figure 3. As a first approximation, adiabatic flow and a perfect gas are assumed.

The weight of the tank is directly proportional to the product of its length and wall thickness. The net variation of tank weight with holding pressure is shown in Figure 4. A composite with the same strength/density ratio called out earlier for the booster tube is assumed. The effect of increased pressure is dramatic particularly up to 5000 psi. At 5000 psi the approximate weight would be 5,000,000 pounds with end caps and miscellaneous. Again, advanced composites in use today could cut that weight by half or more.

Allowing 500,000 pounds for ancillary equipment, an LPA facility should weigh between 4.5 and 8.5 million pounds. It appears that no technology barriers would preclude an even lower minimum. A detailed design effort will be required to better establish weight and performance. Use of processed in-situ material (aluminum, titanium, steel, etc.) on the Moon to build the device should also be considered. For present purposes of preliminary system studies, an Earth-weight equivalent of 5,000,000 pounds transported to the Lunar surface appears reasonable to establish the facility.

An average launch rate of three per day, 257 days per year would yield a total throughput of 1.00×10^8 pounds (45,450 metric tons) per year. Fleet size for the RRV's has not been established, but one mission every other day will only require six vehicles plus backups. Further analysis is anticipated in this area.

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References

(1) O'Neill, G. K., September 1974, Physics Today, p. 32-40.

(2) O'Neill, G. K., September 1975, Hearings Before the Subcommittee on Space Science and Applications of the Committee on Science and Technology - U.S. House of Representatives, p. 111-188.

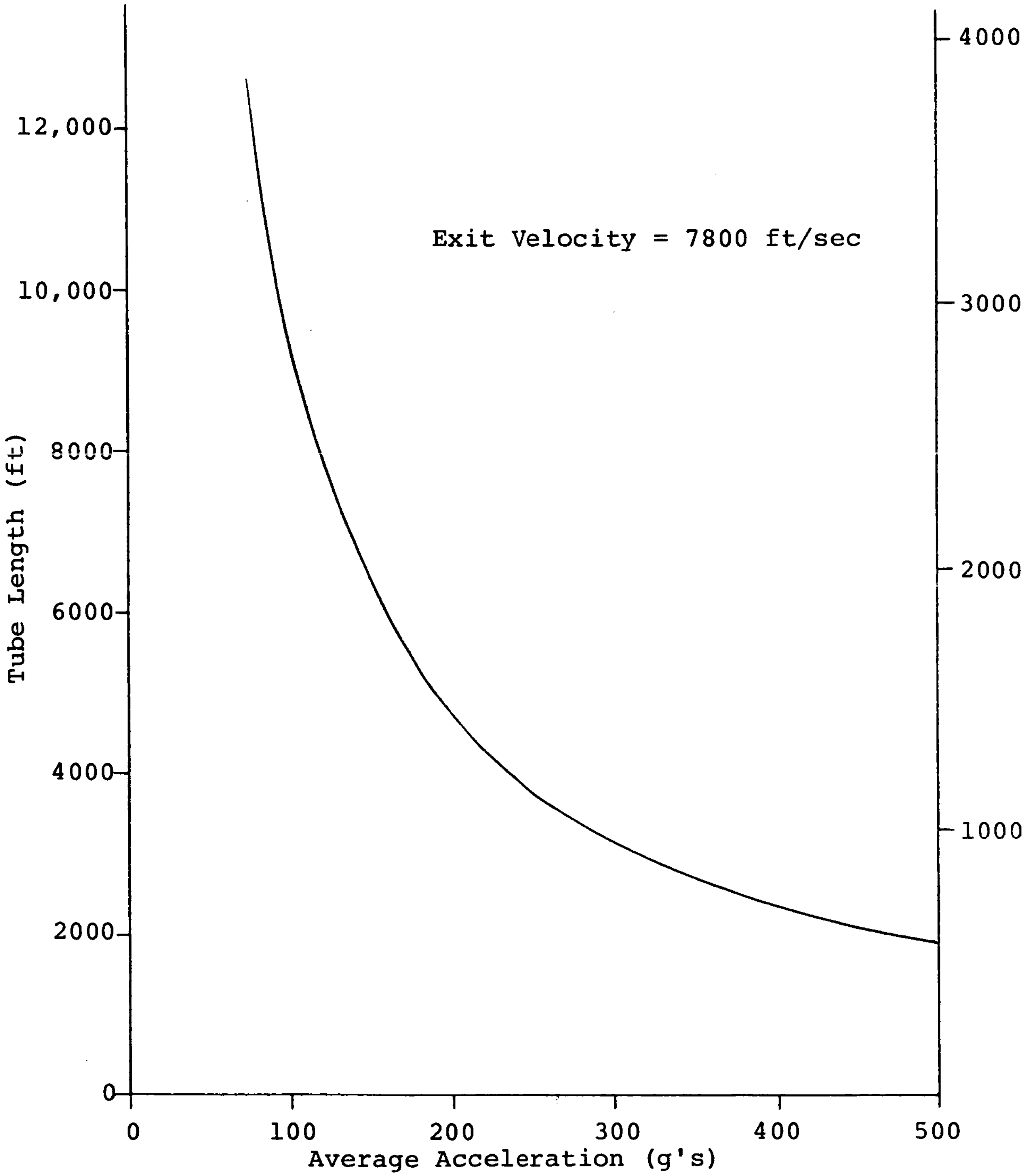

Figure 1. Required Tube Length to Allow Projectile to Reach Lunar Escape Velocity at a Specified Average Acceleration

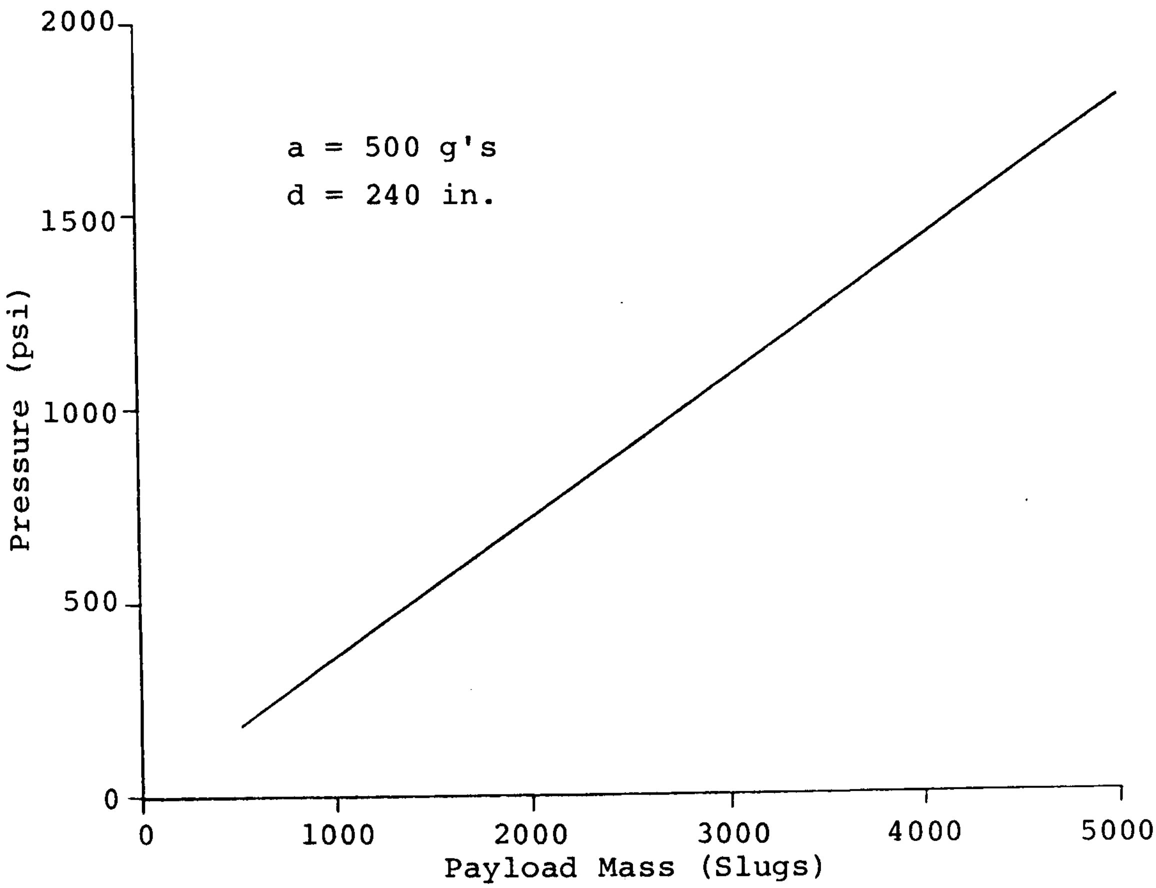

Figure 2. Booster Tube Pressure as a Function of Payload (Projectile) Mass

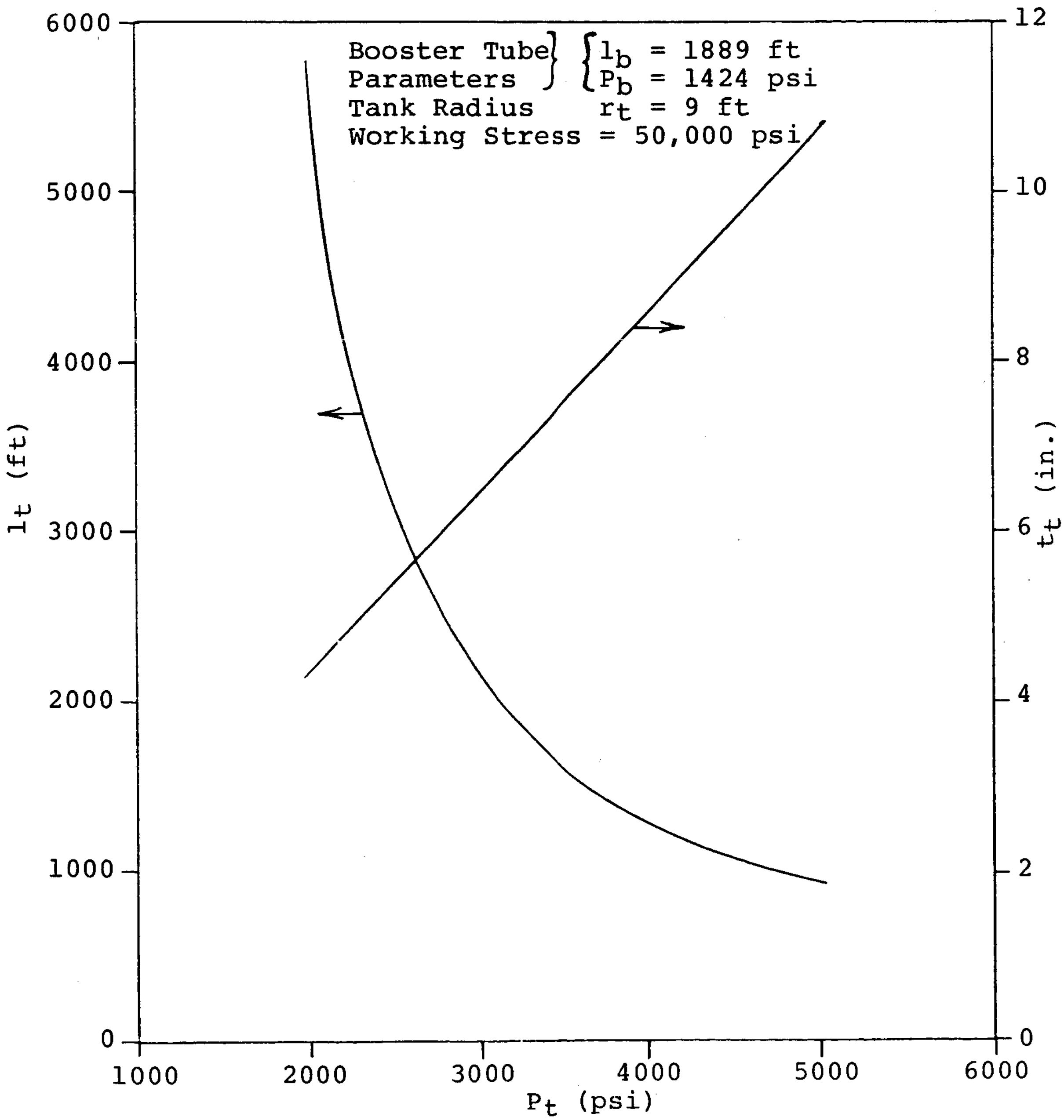

Figure 3. Length and Thickness of Blow-Down Tank as a Function of Holding Pressure

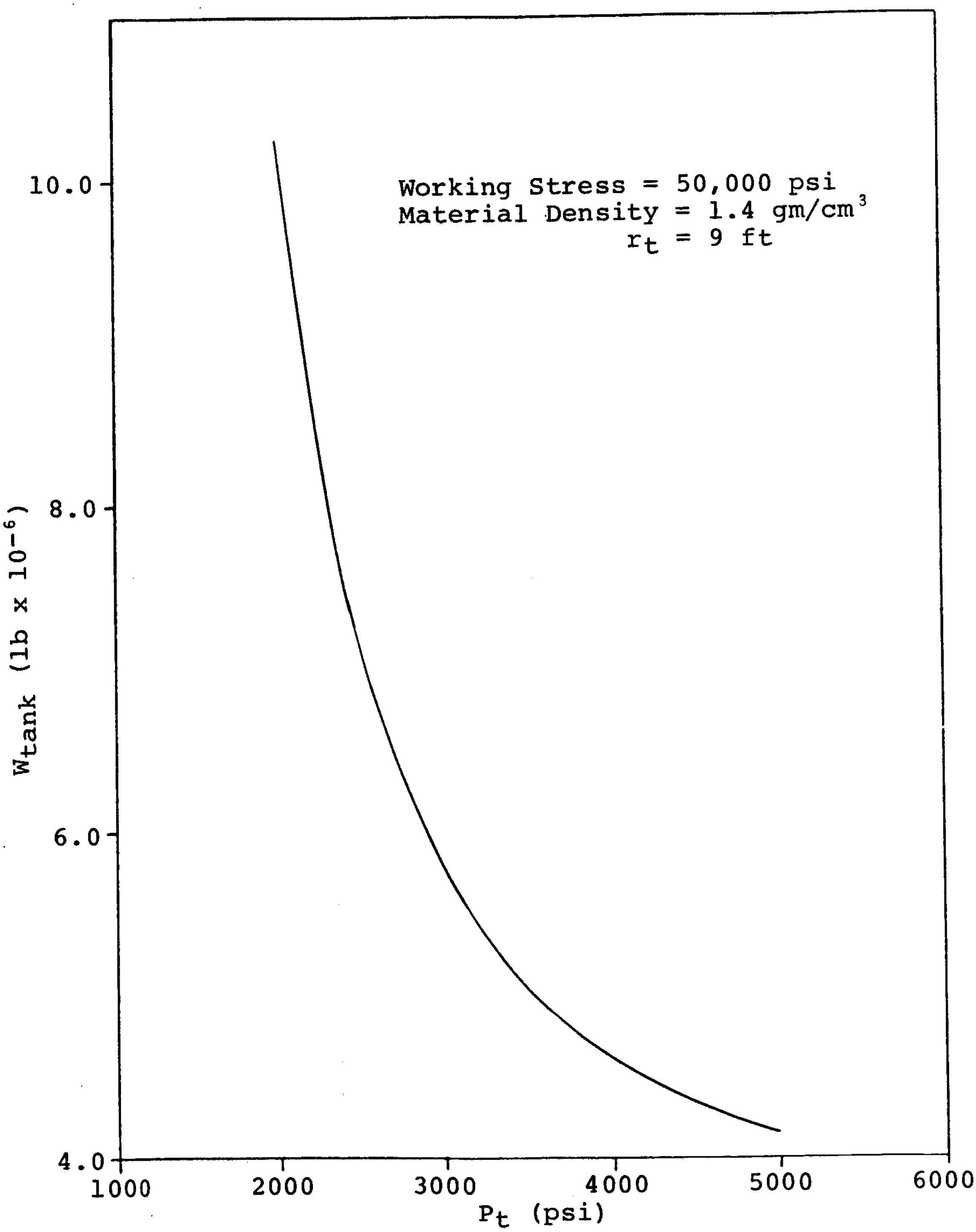

Figure 4. Weight of Blow-Down Tank as Function of Holding Pressure